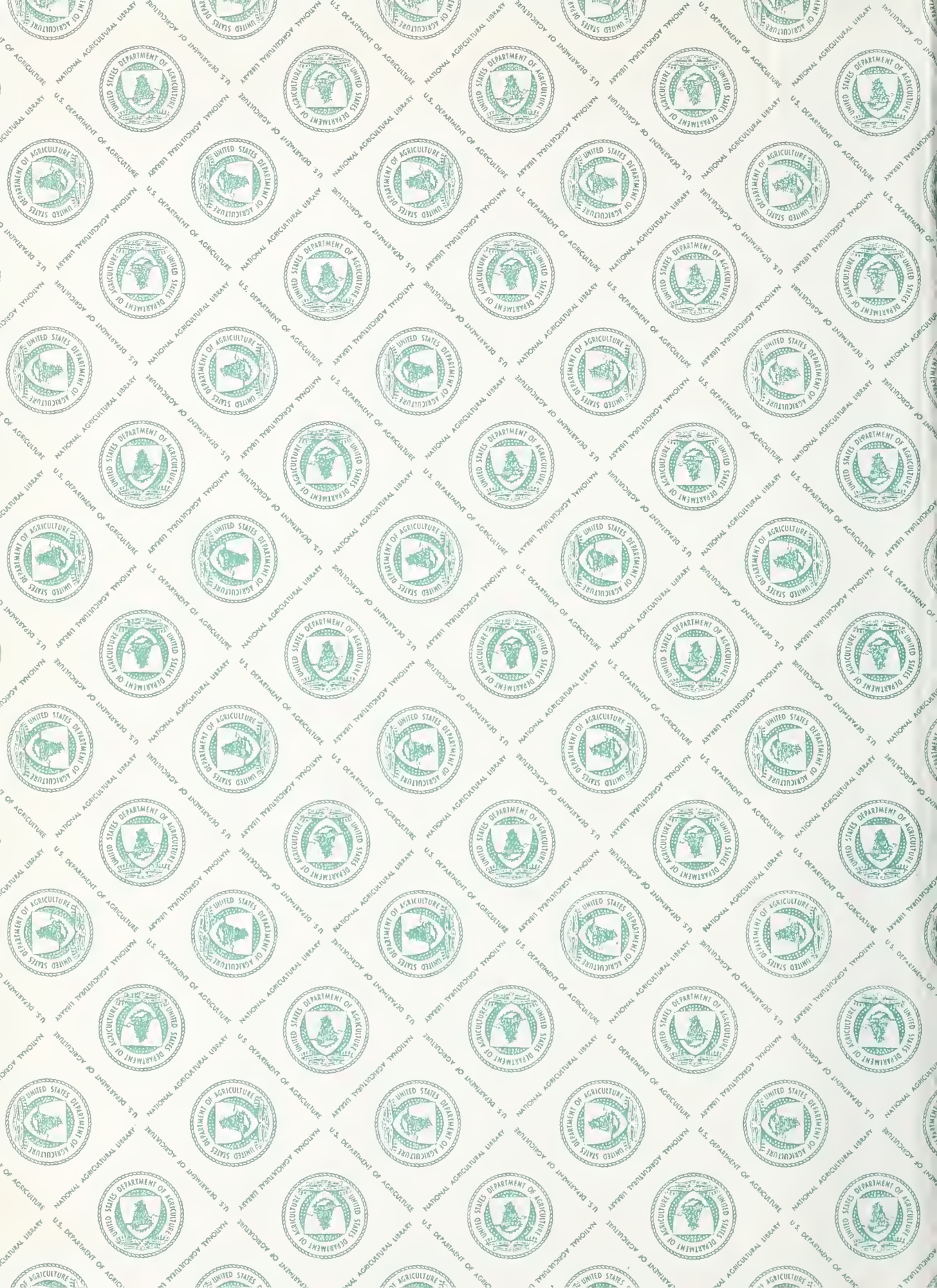
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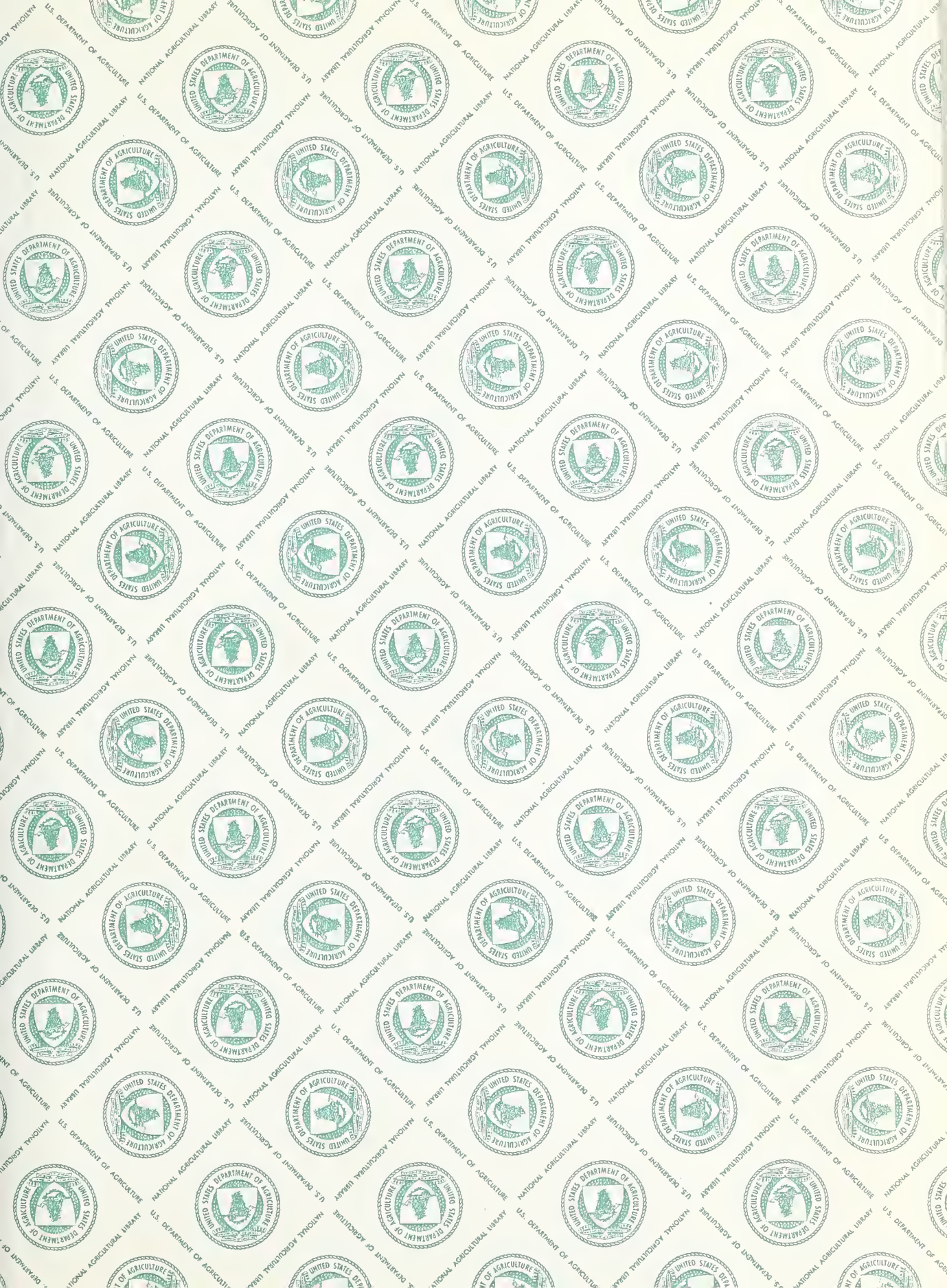
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A Summary of Current Program 4/1/66 *-*

and Preliminary Report of Progress

for 4/1/65 to 3/31/66

SOIL AND WATER CONSERVATION

RESEARCH DIVISION

of the

AGRICULTURAL RESEARCH SERVICE

UNITED STATES DEPARTMENT OF AGRICULTURE

and related work of the

STATE AGRICULTURAL EXPERIMENT STATIONS

This progress report is primarily a tool for use of scientists and administrators in program coordination, development and evaluation; and for use of advisory committees in program review and development of recommendations for future research programs.

The summaries of progress on USDA and cooperative research include some tentative results that have not been tested sufficiently to justify general release. Such findings, when adequately confirmed, will be released promptly through established channels. Because of this, the report is not intended for publication and should not be referred to in literature citations. Copies are distributed only to members of Department staff, advisory committee members and others having a special interest in the development of public agricultural research programs.

This report also includes a list of publications reporting results of USDA and cooperative research issued between July 1, 1965, and June 30, 1966. Current agricultural research findings are also published in the monthly USDA publication, Agricultural Research. This progress report was compiled in the Consumer and Food Economics Research Division, Agricultural Research Service, U. S. Department of Agriculture, Washington, D. C.

UNITED STATES DEPARTMENT OF AGRICULTURE

Washington, D. C.

July 1, 1966

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INTRODUCTION

Our burgeoning population and complex technology are exerting ever-increasing demands on our soil and water resources. Conservation of these vital resources from which man draws his sustenance is imperative. Conservation is rooted in the principle that a resource must not be used faster than it can replace itself. Yet, in some areas, we are ignoring this principle. Aquifers that have been built up over centuries by Nature are being depleted in decades by man. Fertile soil formed during glacial ages is allowed to gully and erode. Rivers that originate from deep springs or snow-capped mountains are fouled with the sewage and effluent from our cities and industries and the erosion-produced sediment from agriculture and construction.

Research-derived management practices have done much to alleviate problems of the past. The Soil Conservation Service, the Bureau of Reclamation and other action agencies have instituted effective technological programs based on these practices. Watershed associations, Soil and Water Conservation Districts, the National Reclamation Association, Irrigation and Drainage Districts and similar resource-using organizations are actively supporting the advance of research-based technology.

Today we are world leaders in soil and water conservation. However, world food developments and changing pressures in agriculture in relation to alternative uses of our resources demand renewed vigor in our research efforts. We are being called upon to help develop worldwide soil and water programs.

The primary objectives of the Soil and Water Conservation Research Division are: (1) To develop efficient management practices for conservation and use of soil resources that will assure an adequate sustained yield of high-quality food and fiber; (2) To gain an understanding of the complex interrelationships of weather, soil, vegetation, topography, geology, and other factors in the environmental ecology as they affect soil and water resources and management practices; (3) To develop more efficient methods for collecting, storing, conveying, and using water resources, and to devise ways of reclaiming wasted or contaminated water for reuse; (4) To develop improved techniques and structures for upstream flood prevention and watershed protection including methods for controlling erosion and sedimentation; (5) To develop improved irrigation and drainage systems involving more economical and effective methods and materials; (6) To evaluate the severity and extent of soil, water, and air pollution, and to provide alternatives or remedial measures, where necessary, to alleviate this pollution.

Selected Examples of Accomplishments--1966

1. Groundwater recharge in Texas High Plains looks promising.

At Bushland, Texas, a simple field system was tested which removed 90 percent of the suspended solids from muddy lake water. During 1965, 61 acre-feet of playa lake water was successfully recharged through 6-inch "domestic type" wells by gravity flow. Mud in runoff water, which remains in suspension indefinitely, is the most serious limitation to water conservation by ground water recharge in the Southern High Plains. The system tested employed a cationic polymer with aluminum sulfate as coagulant chemicals, chemical mixing in a centrifugal pump, a slow mixing in a farm irrigation ditch, and

sedimentation in a basin excavated in the soil near the lake. Finding methods to permit underground storage of water from shallow surface lakes and depressions is an important part of reducing the loss of this water through evaporation.

2. Excessive irrigation increases nitrate-nitrogen losses

Excessive application of irrigation water has generally been assumed to leach plant nutrients from the root zone. The concentration of nitrate-nitrogen below the root zone of sugar beet plots at Twin Falls, Idaho, decreased to a low level earlier in the season, when excessive irrigations were used. These data, when combined with deep percolation losses, indicated that about 35 pounds of nitrate-nitrogen were leached under good irrigation practices, but about 90 pounds per acre were leached with excessive irrigations. In addition to direct losses of applied nitrogen fertilizer, sugar beet yields were lowered 2 tons per acre with excessive irrigation. These data indicate the potential direct economic benefits that can be derived by better control of irrigation water.

3. Streambed Contamination by Pesticides

Chemical analyses of streambed samples taken from the Mississippi River by the USDA Sedimentation Laboratory, Oxford, Mississippi, from Missouri to New Orleans, and from many of its tributaries in the Delta area, showed no general buildup of pesticides detectable at the 0.1 p.p.m. level from on-farm usage. On the other hand, there was heavy contamination in the streams and tributaries that received waste effluents from industrial areas where pesticide materials were manufactured or formulated.

4. Tillage significantly affects rainfall capture and retention

A rough plow tillage treatment captured and retained for crop use three to four times as much water as a plow, disk and harrow treatment in tillage research at Morris, Minnesota. For example, when water was applied at a rate of 5 inches per hour to the two surface conditions on a Barnes soil, the rough-plowed soil captured about 3.8 inches of rainfall before runoff started; whereas, the plowed, disked and harrowed soil captured only about 0.9 inch of water. Similar results were obtained on a Nicollet soil. Tillage practices can significantly influence the capture and retention of more water at the soil surface where it falls, which is particularly valuable in making the most efficient use of our limited water supply.

5. Limited use of irrigation water at critical stages of grain sorghum growth is important conservation practice.

Limited irrigation of grain sorghum in relation to critical stages of plant development has increased irrigation water use efficiencies and decreased water requirements at Bushland, Texas. One 4-inch water application during grain development increased yields from 3160 pounds to 5610 pounds per acre, which means a water application efficiency of 612 pounds per acre-inch for these 4 inches of irrigation water. These data confirm results obtained

the previous two years which indicate that maximum water use efficiency will occur when limited irrigation water is applied at some time between heading and early grain development. Water applied earlier in the season only, and more frequent applications decreased water use efficiency.

6. Midsummer precipitation is an inefficient substitute for stored soil water

About 4 inches of midsummer precipitation were necessary to substitute for 2.5 inches of soil water at planting for an 80-bushel corn yield, according to water use studies in western Minnesota. Since the probability of receiving 4 inches of rain in western Minnesota from July 19 to August 15 is only once every six years, wise resource utilization would dictate that major attention be directed to improving the capture and retention of the more reliable early spring rainfall. This information assumes normal precipitation during the remainder of the growing season and can be helpful in developing optimum management practices for corn production in the western Corn Belt.

7. Salt injury to leaves from sprinkler irrigation with saline water.

Sprinkler irrigation studies with saline water at Norfolk, Virginia, indicate that significant reductions in yield resulting from leaf injury did not occur until salt concentrations approached one-half that of sea water (approx. 18,000 p.p.m.). This concentration is much greater than normally used for irrigation. Vegetable crops varied considerably in the degree to which salts were retained on leaf surfaces, and the degree of leaf injury was not directly correlated with the amount of salt adsorbed. Bean yields were the most seriously affected of the four crops tested. Following one irrigation with water at sea strength, the micrograms of chlorides accumulated per cm^2 leaf area were as follows: corn -125, beans -623, tomatoes -1107, and peppers -2393. Results to date indicate that the effect of foliar-applied salts on leaf injury will depend upon the specific characteristics of the crop, stage of growth applied, and climatic conditions at time of application. It appears that detrimental effects resulting from use of saline water for sprinkler irrigation usually will result from salt accumulation in the soil rather than from leaf damage.

8. Snow Measurement Under Northeastern Conditions

A snow pillow, developed by SWC for snowmelt and water yield studies in the West, was investigated for its suitability and accuracy under eastern conditions. On Sleepers River Watershed near Danville, Vermont, the snow pillow provided a continuous and accurate record of the changes in the snowpack in spite of rains, thick ice lenses, and shallow snowpack. The seasonal data from a 12-foot-diameter snow pillow compared favorably with data from a recording precipitation gage and from snow course measurements. The response of the snow pillow to changes in the snowpack was immediate and to an accuracy of about 0.02 inch. The snow pillow is a promising research tool which will provide more accuracy in predicting water yields and flood-flows under eastern conditions.

9. Corrugated plastic tubing for effective low-cost drainage.

A rapid method for installing plastic drainage conduits has been developed which, when used with a newly developed corrugated-wall plastic tubing, shows promise as a means of attaining effective low-cost drainage. In Ohio, a new tool that is pulled behind a mole plow has been successfully tested for installing a 2-½" O.D. corrugated plastic tube to a depth of 30 inches in a mole-drain channel. Tests on both installation and operation were highly favorable. The corrugations give the tubing longitudinal flexibility. This allows flexing and short-radius coiling for ease of storage, handling and installation. The corrugations also impart radial strength to the tubing for supporting soil loads. The amount of plastic resin required per unit length of pipe is much less for the corrugated tubing than for smooth-walled pipe of comparable strength. Since the cost of plastic tubing is essentially proportional to the amount of material used for a given strength of conduit, corrugating the wall markedly cuts cost. By combining this cost advantage with the much lower installation cost over conventional trenching, it appears that this corrugated-wall plastic tubing and mole-channel installation technique hold considerable promise for achieving effective low-cost drainage.

10. Color of soil surface has a significant influence on plant growth.

The color of the soil surface has a significant influence on plant growth under conditions when the growing season is shortened by an early killing frost. In 1965, corn yields at Fort Collins, Colorado, were 86 bushels per acre with a black soil cover between the rows compared with 48 bushels per acre with a white soil cover. The color was controlled by painting concrete which had been poured between rows 6.5 feet apart. The yield difference was attributed to higher soil temperatures in the spring, lower transpiration and lower leaf temperature on the plots with black concrete compared with the white. Corn plants on the black-covered soil were much greener (chlorophyll content was 48 percent higher) than the plants grown on the white-covered soil. Moreover, they grew much faster early in the spring and matured earlier in the fall. Maturity occurred before the early frost of September 16, 1965. In contrast, corn yields for the two treatments were nearly the same in 1963 (black - 62 bushels per acre, and white - 59 bushels per acre) when the first killing frost did not occur until November 1. This longer-than-normal growing season minimized the adverse effect on yield of the slow growth rate in early spring in the case of plants on the white-covered soil.

11. Radiocarbon Dating Measures Organic Soil Subsidence

Radiocarbon measurements indicate that the peat formation in the Florida Everglades began during late Hypsithermal time (4300 years ago) when the rising sea level slowed down internal drainage and produced a rise in the Everglades' water table. The peat profile developed to a depth of about 12 feet (about 0.0033 feet/year). The present profile is about 4.5 feet

deep. Drainage and agricultural use, initiated about 50 years ago, has destroyed the peat at the rate of 0.10 foot/year. The measurements, made with special facilities at the USDA Sedimentation Laboratory at Oxford, Mississippi, showed that at this rate this valuable natural resource may easily be dissipated in a generation unless improved soil and water management practices are developed and applied.

12. Air temperature is more important than water supply temperature in sprinkler irrigation.

Some agricultural crops cannot tolerate being irrigated with extremely cold water. Other agricultural crops may not produce as well when sprinkler irrigated during critical stages of growth. A theoretical analysis of evaporation from the sprinkler spray indicated that the rate of evaporation is governed by the rate of sensible heat transfer to the falling water droplet. Thus, each droplet resembles the wet bulb of a psychrometer, and the temperature of the water approaches the wet bulb temperature of the air regardless of the initial water temperature. Experimental data obtained at Twin Falls, Idaho, supports this theory. Water delivered to a sprinkler at 41, 63, and 96° F. reached temperatures of 50, 51 and 54° F., respectively, by the time the water reached the crop. The wet bulb temperature was 50.5° F., and the air temperature was 60° F. The results of these studies indicate that water applied by sprinkler irrigation strikes the foliage at a temperature near the wet bulb temperature. The implications of this relationship and the influence on plant growth may be extremely important when sprinkler irrigating sensitive crops, shrubbery, or flowers at critical stages of growth. The potential effects on the crop could be serious in hot, arid areas with low wet bulb temperature. These studies also confirm the fundamental relationships being developed for predicting evaporation losses during sprinkler irrigation.

13. Sediment Yield from Shale Watersheds is High in Southern Plains

Watersheds with soils derived from shales are contributing five times as much suspended sediment to the Washita River and its tributaries as watersheds with sandstone as the parent rock. Measurements by the Southern Great Plains Watershed Research Center, Chickasha, Oklahoma, show a denudation rate of 12.3 inches per 1000 years for the shale areas versus 2.5 inches for the sandstone areas. This knowledge of the sources of sediment production in the Washita River Basin is essential to understanding and determining the effects of an agricultural flood control program on the sediment load of the river.

14. The structure of a tyrosine specific ribonucleic acid.

The structure of a second transfer ribonucleic acid (RNA) has been determined at the U.S. Plant, Soil, and Nutrition Laboratory at Ithaca, New York. The determination of this structure was accomplished in a research program that has been pursued at this Laboratory for the past

eight years. A year ago, a major objective in this program, the determination of the first known structure of a ribonucleic acid, was accomplished. During the past year, the structure of a second RNA, one that transfers the amino acid, tyrosine, to the site of protein synthesis in living cells, was determined. This problem of structure was essentially one of determining the sequence of units called nucleotides in a long-chain molecule.

15. Improved method for sealing cracks in concrete lined channels.

A rapid and efficient method has been developed at the U.S. Water Conservation Laboratory at Phoenix, Arizona, for sealing cracks in concrete lined channels. The cracked area is cleaned with a high-pressure water jet (400 p.s.i.) and a crack sealer is sprayed (1500 p.s.i.) on the wet concrete. Commercially available equipment is used for both these operations. Cracks in a silt- and algae-encrusted concrete lining can be rapidly and effectively located and cleaned with the high-pressure water jet. Materials to seal cracks by covering and/or filling can be rapidly applied and tightly bonded to wet concrete with high-pressure spray equipment. In field trials, 800 ft. of cracks were covered with 10 gallons of sprayable sealer in one hour. This work involved three men, one cleaning with the water jet, one spraying the sealer and one driving the equipment truck. The development of these new repair and maintenance techniques is of growing importance with the increased use of concrete canal linings for reducing irrigation water loss.

16. Loss of agricultural chemicals in runoff.

Concentrations of Atrazine and nitrogenous fertilizer were quite low in washoff (runoff and soil loss) from Cecil soil at Watkinsville, Georgia. Under very severe conditions where a rainstorm of 2-1/2 inches in 1 hour was applied 1 hour after 3 lb/acre of Atrazine was broadcast on cultivated fallow soil, the loss of chemical was only 0.50 lb/acre, or 1.4 p.p.m. in the washoff. When the chemical was applied 96 hours before the rainstorm, the loss was only 0.33 lb/acre, or 0.6 p.p.m. in the washoff. A rainstorm of 5.0 inches in 2 hours, applied immediately after 200 lb/acre of N as ammonium nitrate was broadcast, caused losses of only 2.3 and 0.3 percent of the N from fallow soil and grass sod, respectively. Losses from more frequent low volume rainstorms should be less than these meager amounts. Also, these tests were made where 100 percent of the contributing area was treated with the chamicals. Concentrations of chemicals should be lower where only a portion of a watershed is treated but runoff comes from the entire watershed.

EXAMPLES OF RECENT ACCOMPLISHMENTS OF THE STATE AGRICULTURAL EXPERIMENT STATIONS

1. Behavior of Pesticides in Soils

The problem is to determine what happens to pesticides as a basis for informed action to control harmful effects of pesticide residues. During the

past year, researchers at the Agricultural Experiment Station of Cornell University identified 2,4-dichlorophenol as a metabolite of 2,4-dichlorophenoxyacetic acid by Arthrobacter. Further work showed that acid side chains are removed from other compounds similar to 2,4-D, forming the corresponding phenols, and representing the first step in the degradation of phenoxy acid herbicides. It was found further that after adaptation to 2,4-D, the resulting organism could decompose the matabolite (2,4-dichlorophenol), but when grown on a different phenoxy acid, it would not decompose its metabolite. Thus, strains or populations of microorganisms may adapt to a herbicide but become ineffective for destruction of the metabolite of another. This implies that application of one herbicide soon after application of another related one may cause an accumulation of harmful metabolites.

2. Waste Water Renovation and Conservation

Where much of the water supply in an area is obtained from the ground water reservoir, virtually all of the water is lost when it passes through a sewage treatment plant and is disposed of in a natural watercourse. The outflow from such plants is relatively rich in nutrients. When discharged into low flow streams, it increases plant life in the stream and makes the oxygen situation unfavorable for fish life.

At Pennsylvania State University, an interdisciplinary approach is being taken in investigations on the disposal of the effluent from a sewage treatment plant on agricultural and forest lands. Chlorinated effluent was applied to corn, wheat, red clover, alfalfa, idle farm land, mixed hardwoods, and red pine plantations at rates of 1 and 2 inches per week through a revolving sprinkler irrigation system.

Concentration of nitrate in the soil water below 12 inches in the effluent irrigated plots was reduced 68 to 80 percent; phosphorus, 99 percent; and detergent, 95 to 98 percent. Nitrogen, phosphorus, and detergents are primarily responsible for the degradation of stream quality. It was estimated that, on plots receiving 2 inches of effluent per week, one million gallons of high quality water per acre were recharged to the ground water reservoir for potential reuse during a 5½ month period.

3. Reclamation of Strip-Mined Areas

Much more rapid and successful reclamation of spoilbanks can be achieved if present methods are directed toward basic land improvement rather than superficial landscaping.

Research at the Ohio Agricultural Research and Development Center has shown that when spoil materials are exposed to the atmosphere, soluble salt production begins intensively.

Previous practice has been to grade spoil banks to a topography resembling natural land configuration. Instead the land should be shaped for greater rain retention and absorption.

The rate of removal of soluble salts and acid materials varies directly with the amount of water passing through and draining from the spoil material. With land shaping for maximum rainfall retention, annual rates of salt removal have averaged 5 to 10 tons per acre and reached an amount of 130 tons per acre in one case. Revegetation, the second stage of reclamation, can be accomplished when toxic materials are reduced to a tolerable level.

4. Nitrogen Management for Oranges

Many methods have been used in the past to determine the amount of nitrogen fertilizer to use. Since all of these methods had certain weaknesses, orange growers were applying more nitrogen than was needed, primarily as insurance that an adequate supply would be present in the soil. During recent years, scientists at the California Agricultural Experiment Station have developed leaf analysis as a practical tool to aid growers in planning an efficient nitrogen program. Leaf analysis measures the percentage of nitrogen in a specified leaf, integrating the effects of many variables which influence the level of nitrogen in trees. This technique is now widely used by California orange growers.

Adoption of leaf analysis has resulted in lower levels of nitrogen fertilization, saving the growers of the State approximately 3 million dollars annually. Controlled nitrogen fertilization also has resulted in higher fruit quality--better color, finer textured and thinner peels, higher juice percentage, and a higher vitamin C content.

5. Leveling Rice Land in Water

Attempts to change the natural slopes of dry rice land by use of the land plane (land leveler) have been largely unsuccessful. However, researchers at the Louisiana Agricultural Experiment Station recently have devised a system for leveling rice land in water.

Leveling in water has the advantages over dry leveling of allowing a farm operator to use equipment commonly found on a rice farm, and to take advantage of water wave action to help keep top soil in place and to move lower more compact soil.

By leveling (forming) rice land as much as 80 percent of the levees can be removed with adequate slope maintained for drainage. Leveling in water to remove levees and create a uniform slope, may be done in 2 to 4 hours per acre by one man using a large tractor and straight blade implement.

Pumping time and water use on some farms have been reduced by as much as 50 percent after leveling, with some farmers reporting yield increases as

high as 1,000 pounds of rice over their highest previous yields. Well over 100,000 acres of Louisiana rice land have been leveled using this method.

* * * * *

As a step toward implementation of the recommendations for a National Program of Research for Agriculture made jointly by the Association of State Universities and Land Grant Colleges and the USDA, a section has been added to each of the Areas in this report. It comprises a list of the related publications of the State Agricultural Experiment Stations in addition to those heretofore reported covering the results of USDA and cooperative research. In future years, it is anticipated that information will be available to permit reporting of achievements resulting from State research in a format comparable to the present reporting of the USDA and cooperative research.

AREA 1: SEDIMENTATION PROCESSES IN RELATION TO WATERSHED DEVELOPMENT AND PROTECTION

Problem: Most sediment problems are associated with the unwanted deposition of eroded material in reservoirs, harbors, stream channels, streets and highways, or on floodplain lands. In addition to these deposition problems, sediment in streams damages fish and wildlife and it must be removed from domestic and industrial water supplies. Sediment in transport, the imbalance of the sediment load in streamflow because of alterations or impoundments in channel systems, and even erosion control practices in tributary watersheds, can also create major sediment problems. In many parts of the country, abatement of sediment damages is one of the primary justifications for watershed protection and development programs.

The processes of sedimentation are complex, but an understanding of these processes and the factors controlling them is essential for the development of practices and programs for solution of sediment problems. The relation between sediment load, streamflow, land use and watershed characteristics must be clarified through research. Improved criteria are also needed for computing the bedload movement of sand, gravel and other coarse debris; for predicting the rates of silting, the sediment trap efficiency, and the distribution of sediment in floodwater detention reservoirs; and for describing the morphology of stream channel systems having beds and banks of alluvial or cohesive soil materials.

This research seeks new and improved criteria for evaluating various sedimentation processes, for identifying sediment sources, and for developing methods for sediment control and stream channel stabilization.

USDA AND COOPERATIVE PROGRAM

The Division carries on a continuing long-term program of both basic and applied studies of sedimentation processes, involving hydraulic and agricultural engineers, soil scientists, soil physicists, geologists, chemists, and botanists, for the purpose of developing and proving new information useful in the solution of various sediment and stream channel problems. Intensive research in all aspects of sedimentation is carried out at the USDA Sedimentation Laboratory, Oxford, Mississippi, where more than one-half of the Division's sedimentation research personnel are headquartered. At other locations, attention generally can be given only to the most critical problem of the region.

All of the studies are cooperative with the respective State Agricultural Experiment Stations. In addition, cooperation is maintained with The Illinois State Water Survey Division, The University of Mississippi, The Oklahoma State University, and The University of Oklahoma Research Institute.

A total of 23.5 scientific man-years was devoted to research in this area in the 1965 reporting period. Of this number, 13.6 man-years were devoted to studies of sediment sources and yields from agricultural watersheds; .9 to rates and processes of reservoir silting; 3.4 to mechanics of sediment entrainment, transportation and deposition; 4.6 to stream channel morphology and means and measures for channel stabilization; 1.0 to valley sedimentation rates and distribution.

PROGRAM OF STATE EXPERIMENT STATIONS

A total of 2 scientific man-years is devoted to this area of research.

PROGRESS -- USDA AND COOPERATIVE PROGRAMS

A. Sediment Sources and Yields from Agricultural Watersheds

1. Sediment sources. A survey of the debris basin and of the reach above a dam on the Little Hoosic River, near Berlin, New York, indicated that deposition was predominant in the debris basin to within 250 feet of the dam, with about 0.2-foot degradation of the channel thalweg from 250 to 1,800 feet upstream from the dam. This degradation, together with the evidences of bank cutting from surveyed cross sections, shows the stream channel to be the source of much sediment deposited in the basin. (SWC 1-a1)

Four years of observation at the North Mississippi Branch Agricultural Experiment Station, Holly Springs, Mississippi, showed that runoff from 0.25-acre plots in corn was 1.4 times greater and soil loss was 4.3 times greater for poor management than for improved management. Mean annual corn yields were 17 bushels and 60 bushels per acre, respectively. Soil losses were 12 to 16 tons per acre per year when less than 1 ton per acre of plant residue was left on the soil surface, whereas 5 to 6 tons of crop (corn) residue per acre gave almost complete control of the sediment source. (SWC 1-bE1)

Sediment production from a typical small gully (0.15-acre in surface area and 5 to 15 feet deep) in the Southern Mississippi Valley Silty Uplands Land Resource Area averaged about 100 tons per acre annually for the 2-year period 1964 and 1965, according to findings of the USDA Sedimentation Laboratory, Oxford, Mississippi. This represents an annual denudation rate of about two-thirds of an inch. These soil losses are about one-third of those previously determined by other investigators for a typical, but larger and deeper, gully located in similar geologic materials. (SWC 1-bE1)

Photogrammetric methods are being evaluated at the Central Great Plains Experimental Watershed near Hastings, Nebraska, as method for determining depths and volumes of erosion and deposition over a relatively long time from complex agricultural watersheds. The results of this study show that neither the high-altitude photos (13,000 feet) nor the lower altitude photos (2,700 feet) are of sufficient quality or control to determine net erosion or micro changes in land surface of small (50- to 500-acre) watersheds. A new aerial survey will be made at an altitude of about 1,400 feet and new photogrammetric maps developed in an effort to determine the criteria needed to obtain maps that are sufficiently accurate to measure important micro changes in land surfaces. (SWC 1-d2)

Measurements of sediment transport in the Washita River and its tributaries by the Southern Great Plains Watershed Research Center, Chickasha, Oklahoma, showed that sandstone-based areas had lower sediment production rates than shale-based areas. Based on the rates measured during the 4-year study, the sandstone areas would lose 2.5 inches of soil material per 1,000 years, whereas the shale areas would lose 12.3 inches. (SWC 1-e1)

At Cherokee, Oklahoma, unit soil loss from wheat plots increased as the plots became shorter. The 33-foot-long plots lost an average of 2.1 tons per acre, whereas the 167-foot-long plots lost 0.94 ton per acre. Plots extended downslope from the top of a terrace ridge; consequently, the shorter the plot, the greater its average land slope because proportionally more of the plot was on the back slope of the terrace. (SWC 1-e1)

A general geomorphic survey of the Walnut Gulch Experimental Watershed, Tombstone, Arizona, has been essentially completed. The survey information indicates that the source of modern sediments is mainly the channel walls, and secondarily the remainder of the watershed. It is apparent, however, that the sediment supply process must take place in a succession of steps and, although the immediate source of sediments in the streams is mainly derived from channel cutting, the valley sources are probably to some degree being replenished by sediment eroded from higher on the watershed. Considerable sediments are currently moving out of rills and minor gullies, extending into the headwaters areas. An objective of this research is to understand the interrelated factors affecting quantities and time phasing involved in the march of erosional materials from their original sources into the major streams. (SWC 1-g1)

Detailed topographic surveys were completed for mapping the Lucky Hills subwatersheds within the Walnut Gulch Experimental Watershed, Tombstone, Arizona, to 1-foot contour intervals, with a horizontal scale of 1 inch equals 20 feet. These base maps will be used to evaluate the morphometric features of these subwatersheds. (SWC 1-g1)

Sampling of deposited sediments in the main channel of Walnut Gulch Experimental Watershed, Tombstone, Arizona, was started in the spring of 1965 and is continuing. Sets of transverse samples are being collected at approximately 1-mile intervals along the stream and at tributary confluences. Forty-three sites have been sampled to date. Mineralogic and other analyses are planned to identify sources of the sediments. (SWC 1-g1)

2. Sediment yields. Data from several storms at the North Mississippi Branch Agricultural Experiment Station, Holly Springs, Mississippi, where plot runoff was instant-sampled, indicated that a large proportion of the total sediment from a particular storm event occurs in a relatively short time during early stages of runoff. Measurement from a 1.45-acre terraced watershed indicated a 76-percent reduction in sediment when compared with data collected from the same area prior to terracing. (SWC 1-bE1)

Investigations by the USDA Sedimentation Laboratory, Oxford, Mississippi, have shown that sediment yield from Pigeon Roost Creek Watershed can be predicted satisfactorily using a gross erosion equation for cultivated land and gullied areas only. For 12 subwatersheds in the study area, the computed gross erosion from these two major sediment sources correlated better with measured sediment yield than the erosion computed from the entire watershed. Such a procedure simplifies the computations. These data also suggest that sediment production has been overestimated in the past, especially for the low-yield conditions. (SWC 1-bE1)

Investigations by the North Central Watershed Research Center, Columbia, Missouri, showed the marked effect of terraces on sediment yield from watersheds in corn and grass, near Treynor, Iowa, in the Iowa and Missouri Deep Loess Hills Land Resource Area. On an unterraced watershed with corn on the contour, sediment carried in runoff from 75 acres totaled 4400 tons for the year, or 60 tons per acre. Although the deep gully in this watershed was severely eroding in depth and extent, it contributed only one-sixth of the total sediment. Sheet and rill erosion accounted for five-sixths of the total. Sediment concentration in the May storms reached 200,000 parts per million; that in the September storms of equal magnitude was less than 100,000. In this same area, sediment from a terraced watershed and from a grassed watershed totaled only 1 ton per acre. (SWC 1-c1)

Large daily fluctuations in sediment concentrations were observed in two large-discharge, low-concentration flows on the Washita River at Chickasha, Oklahoma. The concentrations were lowest at midday and highest

during the night. No explanation of this difference is presently available but it may be associated with water temperatures. (SWC 1-e1)

Relatively few new sediment samples were collected in 1965 on the Walnut Gulch Experimental Watershed, Tombstone, Arizona, because of below-normal flows. However, completion of new office and laboratory facilities for the Southwest Watershed Research Center at Tucson, made possible analyses of a backlog of suspended sediment samples collected in 1963 and 1964. With data from these analyses, further efforts were made to develop sediment rating curves for Walnut Gulch. A rating curve for total suspended load, with a very broad error band may be possible at Flume 6, representing the upper 33 square miles of Walnut Gulch Watershed. However, the data strongly indicate that no relationship of load to discharge can be developed for Flume 1, at the outlet of the 58-square-mile watershed, because of a wide variation in transmission losses in the lower channel reaches. Sediment transmission losses are proportionately less than the water losses, with resulting wide fluctuation in the suspended load concentrations in relation to the flow. (SWC 1-g1)

An installation was completed for collecting depth-integrated samples at the main outlet station of the Alamogordo Creek Experimental Watershed in New Mexico. From the few samples so far analyzed, it appears that total suspended sediment loads for Alamogordo Creek are similar to those for Walnut Gulch. However, suspended loads in Alamogordo Creek contain more fines than in Walnut Gulch, and fewer of the coarse fractions. (SWC 1-g1)

3. Roadside sources of sediment and control.

Investigations of mulching methods for stabilizing newly prepared and seeded highway backslopes were extended at Cartersville, Georgia. These studies were the first to quantify runoff and soil movement for various mulching treatments on slopes of 40 percent. Findings revealed that 24 tons of grain straw per acre provided adequate protection to newly prepared and seeded 2½:1 backslopes when subjected to simulated 1-year frequency storms, 1.3 inches of rain in 30 minutes. However, when subjected to a 10-year frequency storm, 2.7 inches in 60 minutes, two treatments stood out as superior; these were the "whisker dam," called the Florida method, which permitted 1.0 inch of runoff and 10 tons per acre soil loss, and the direct surface mulch, called the Cartersville method, which permitted 1.1 inches of runoff and 11 tons per acre soil loss. Bare, unprotected backslopes permitted 1.6 inches of runoff and 97 tons per acre soil loss for the 10-year storm. Six months after planting and testing, satisfactory grass stands had been established with all mulch treatments. (SWC 1-b1)

A study of the adaptability of species and species-mixtures for roadside stabilization in Georgia showed three varieties of crownvetch to rank differently in seedling vigor and cover. Chemung was best; Emerald was second; and Penngift was third. Fescue or fescue plus

crimson clover provided excellent roadside cover. Nitrogen from the crimson clover stimulated the fescue. English ivy was a failure at all locations. Bahiagrass gave the most economical cover on light-textured soils in southern Georgia. Better stands and growth of bahiagrass, when planted alone or in mixture, were obtained on clay soil than on sandy soil. In general, the best stands of bahiagrass were obtained from June seedings; however, the stands obtained appear to be tied closely with soil moisture conditions, since good stands have also resulted from March and September seedings with ample rainfall. In mixed plantings, excessive competition from lovegrass, common bermudagrass, and fescue reduced stands of bahiagrass. (SWC 1-b1)

4. Sediment measuring devices. At the USDA Sedimentation Laboratory, Oxford, Mississippi, an americum-241-activated sediment concentration gage was calibrated, in cooperation with the International Atomic Energy Agency (IAEA), Vienna, Austria, in hydraulic flumes with varying velocities and sediment concentrations. The IAEA gage is designed for determining sediment concentrations without taking samples. The unit is not automated and has been kept simple and lightweight for ease of handling in the field. The IAEA gage, operating as an integral spectrometer, functioned well and was capable of measuring sediment concentrations as low as 1,000 p.p.m. (SWC 1-bE1)

The USDA Sedimentation Laboratory, Oxford, Mississippi, continued active cooperation with the U.S. Atomic Energy Commission; the Federal Inter-Agency Subcommittee on Sedimentation; and Parametrics, Inc., Waltham, Massachusetts, in testing of the nuclear suspended-sediment gage developed by Parametrics under contract with AEC. This gage, designed for remote, automated operations, was recalibrated in the laboratory and prepared for field operations. (SWC 1-bE1)

Field tests were continued at the USDA Sedimentation Laboratory, Oxford, Mississippi, on the Traversing Slot Sampler, and the N-1 and N-2 Coshocton-type wheel runoff samplers. In addition, plans were prepared for a model N-3, 3-ft. Coshocton-type runoff sampler, and hydraulic tests made. The capacity is about 5 c.f.s. and the volume extracted by the sampler is 1/300th of the total runoff. (SWC 1-bE1)

Sediment concentrations of streamflow obtained with a bottling-type pumping sediment sampler, operated by the Southern Great Plains Watershed Research Center, Chickasha, Oklahoma, were compared with concentrations of samples obtained manually with depth-integrating suspended sediment samplers. The agreement was very good for one of the two runoff events selected for the comparison tests. The equation relating the concentrations had a correlation coefficient of 0.92, significant at the 1 percent level. The relatively poor agreement for the other runoff event is believed to have been caused by the shifting streambed covering the lower pump intake for a part of the time. (SWC 1-e1)

Sediment concentrations, on the Washita River and tributaries, obtained from a single-vertical traverse of a depth-integrating sampler were compared with concentrations obtained from multiple-vertical traverses (the equal transit rate method) by the Southern Great Plains Watershed Research Center, Chickasha, Oklahoma. For selected single-verticals, good agreement was found. The single-vertical technique offers promise of greatly reducing the work required to obtain a measure of the sediment content of a stream. (SWC 1-e1)

Comparison of sediment load samples obtained with an automatic pumping sampler and a depth-integrated manual sampler indicate close agreement at Flume 6 on the Walnut Gulch Experimental Watershed, Tombstone, Arizona. However, the pump sampler intake is located at the bank on the outside of a curve in the stream channel, where the flow velocities are as high as or higher than at midstream where the depth-integrated samples were taken. (SWC 1-g1)

5. Streambed contamination by pesticides. Chemical analyses of streambed samples taken by the USDA Sedimentation Laboratory, Oxford, Mississippi, from the Mississippi River, from Missouri to New Orleans, and from many of its tributaries in the Delta area, showed no general buildup of pesticides detectable at the 0.1 p.p.m. level from on-farm use. On the other hand, there were heavy concentrations in the streams and tributaries that received waste effluents from industrial areas where pesticide materials were manufactured or formulated. (SWC 1-bE1)

B. Rates and Processes of Reservoir Silting

Data on reservoir silting contained in USDA Misc. Pub. 964, "Summary of Reservoir Sediment Deposition Surveys Made in the United States Through 1960," are being analyzed at the USDA Sedimentation Laboratory, Oxford, Mississippi. Although the analyses are incomplete, some of the first observations are: (1) Almost 65 percent of 990 reservoirs reported have an individual storage capacity of less than 1,000 acre-feet; (2) eighty-three large reservoirs contain more than 90 percent of the total original storage capacity of all reservoirs reported; (3) the average annual rate of storage depletion is much higher in the smaller reservoirs, decreasing from about 2.5 to 0.2 percent annually as reservoir capacity increased from less than 10 to more than 100,000 acre-feet. (SWC 1-bE2)

At Fort Collins, Colorado, a laboratory study of delta development induced by floodwater-retarding and sediment-detention structures was initiated. A large flume facility has been constructed for studying delta development in three dimensions. Preliminary analysis of data and observations to date indicate that patterns of delta development may be predicted from some knowledge of the geomorphology of the stream flowing into a reservoir. A study has also been conducted concerning the distribution and sorting of sediments in the delta during its development. Knowledge of the mechanics of delta development will assist engineers in controlling

the pattern of development so that sediments will not interfere with other uses of reservoirs. (SWC 1-18(d3))

C. Mechanics of Sediment Entrainment, Transportation and Deposition

1. Mechanisms of sediment diffusion. At the State University of New York at Buffalo, an investigation is being made of the complex diffusion mechanism in turbulent flows that entrains, mixes, and transports sediment through the fluid medium. The objective of this study is to develop theoretically founded relations for sediment entrainment and movement based on a correlation of sedimentation processes with the turbulent and diffusive properties of flow. In the analytical phase of the investigation, a simple, rapid, and accurate numerical technique was found for solving a form of the convective-diffusion equation applicable to the experiments. Solutions for the spatial distribution of sediment concentration were developed for sediment sizes and flow conditions of interest. The technique of solution is applicable to any homogeneous parabolic partial differential equation with constant coefficients, and accurate results can be obtained rapidly from a digital computer. In the experimental phase of the investigation, measurements will be obtained for determining the functional relations expressing the diffusion coefficients, especially their dependence on flow conditions and concentration. The final phase of the investigation will be to compare the experimental results with the theoretical relations. Basic investigations of this nature will lead to refinements in mathematical equations for calculating rates of sediment transport in stream channel systems. (SWC 1-a1)

2. Bedload transport. Model tests of streambed particles at the USDA Sedimentation Laboratory, Oxford, Mississippi, confirmed that the drag coefficient of a spherical particle on a streambed is the same as that for a particle in free fall--at least, between the particle Reynolds' numbers less than 100, the so-called lift-force on a streambed particle is directed downward, which tends to inhibit motion; but, in the Reynolds' number range from 100 to 3,000, a positive lift-force exists, which facilitates particle motion. (SWC 1-bE3)

A statistical study of water surface slope variations, under equilibrium-flow conditions, was made in a 100-foot sandbed flume at the USDA Sedimentation Laboratory, Oxford, Mississippi. The coefficient of variation for slope measurements was 15 percent for smooth and for antidune-bed conditions, but increased to 40 percent for dune-bed conditions. The large coefficient of variation reflects highly unstable surface slopes and emphasizes the need to use suitable techniques and replicate measurements to obtain reliable slope estimates. (SWC 1-bE3)

Another modification of the Einstein procedure for computing bed material transport has been devised that utilizes the relationship between measured velocities and the hydraulic radii of a reach, and does not require suspended sediment samples. Called the "Effective Slope Method," it has

yielded results at the USDA Sedimentation Laboratory, Oxford, Mississippi, in close agreement with the more complex "Modified Einstein Method" for the few cases where it has been tried. (SWC 1-bE4)

The bedload sampling effort, started in 1964 on the Calleguas Creek Watershed, in the southern California coastal area was continued in sampling the overfall at a number of highway drainage and channel stabilization structures. The slot sampler originally developed for this was modified; rather than passing the suspended load through the bedload samples and sampling it separately, a container was added to collect a 2-gallon total load sample. The samples were subsequently split to quart size for analyses. Total load concentrations in samples collected in 1964-65 winter storm flows ranged from 0.2 percent to 5.0 percent, averaging about 2 percent. The bedload fraction averaged around 20 percent of the total load. (SWC 1-g1)

D. Stream Channel Morphology and Means and Measures for Channel Stabilization.

1. Channel morphology. Severe degradation was observed in the Earsing cutoff of Buffalo Creek at Gardensville, New York, where studies of stream channel processes are being conducted. The degradation has exposed material below the alluvium, undermined the bank revetment, and endangered the bed sills built for channel stabilization. One or a combination of the following three factors might have caused the degradation: (1) Construction of highway bridge for the New York Thruway downstream from the reach may have deepened the channel locally; (2) Gravel removal in the upstream reaches may have partly starved the stream of sediment; and (3) the general reduction in sediment load through channel stabilization works may have contributed to the starving of the stream of sediment required for gradient stability. (SWC 1-a1)

In the channel reaches of Barber Creek near Athens, Georgia, where runoff and sediment discharge from 95 percent of the area are modified by flood detention structures, the bed continues to slowly degrade, the bottom width to become narrower, the top width to become greater, and the cross-sectional area to become larger, after 4 years of observation. The stream is about 16 ft. wide along this stretch. The bed and bank materials that have been lost in the channel enlargement have apparently been partly deposited in downstream-dredged reaches. In 4 years the bed has degraded about 1 ft. on the average, and the cross-sectional area has increased about 16 square feet. (SWC 1-bE4)

Selection of channel sites in southeastern Nebraska was completed for studies involving the stability of stream channels as related to hydrologic, hydraulic, periphery materials, and other environmental factors. Of the 150 channels selected, 101 have been surveyed and soil samples have been collected on 51. Good progress is being made on completing laboratory analysis of these samples at Hastings, Nebraska, and data are being

tabulated for computer analysis. During 1965, one computer program was written for determining the shear stresses, friction velocities, shear velocities, mean velocities, hydraulic radii, water surface profiles, and Reynolds and Froude numbers. The second computer program is currently being tested for determining the channel geometry. (SWC 1-18(d3))

Resurveys of selected cross sections of the Washita River and tributaries, by the Southern Great Plains Watershed Research Center, Chickasha, Oklahoma, showed net deposition during the past year in six of the seven study reaches. Most deposition was on the floodplain or on the channel banks. The study reaches, ranging in length from 500 feet to 1430 feet, are believed to be too short to provide a meaningful measure of changes in a long stream reach. Increasing the length of the study reaches would be desirable, but the use of conventional cross-section surveying techniques would then become unduly burdensome. Aerial photogrammetry combined with conventional surveys and covering more of the stream might be the answer. (SWC 1-e2)

In studies of channel morphology in the Washita River Basin, a comparison of depths to rock obtained by drilling measurements and by seismic methods was made by the Southern Great Plains Research Watershed Center, Chickasha, Oklahoma. The seismic method was faster in the field, but the time saved there was offset by the time required for interpretation of the record. Errors by the seismic method ranged from 0 to 25 feet in a total depth of approximately 100 feet. It was concluded that the drilling method should be used whenever possible. (SWC 1-e2)

Unusual opportunity has been afforded for study of aggradation-degradation processes in various channel reaches of the Walnut Gulch Experimental Watershed, Tombstone, Arizona, as the sediment transport regime has been disturbed and seeks restoration, following the installation of each of several tandem runoff-measuring flumes. The flume inverts are generally constructed a few feet above the previous channel bed, to assure necessary contraction for critical flow in the structure, and borrow pits are dug immediately upstream, for sand and gravel used in the flumes' construction. Enough sediments are deposited in a few flow events to fill the borrow pits and raise the approach channel beds to the invert levels of the new flumes. After this, aggradation of the channel progresses upstream at a diminishing rate. There was some indication from surveys made in early 1965 that a second wave of aggradation was following the first back upstream, re-establishing essentially the original channel gradient for a short distance above the flume. In other cases, waves or bars of sand and gravel have been observed moving progressively downstream with successive flows, prior to filling the approach channels of new flumes to their invert levels. The patterns, rates and extent of aggradation upstream from these flow-measuring structures should continue under observation and measurement over several seasons, to predict their ultimate effect on channel morphology. (SWC 1-g2)

2. Channel stabilization. The experimental cellular concrete block revetment on Buffalo Creek near East Aurora, New York, continues to remain in good condition. Repairs were made to one broken block along the bottom edge which was allowing subgrade materials to flow out. (SWC 1-a1)

3. Stability of channels in cohesive materials. Study of the principles of stable channels in cohesive materials continued at the USDA Sedimentation Laboratory, Oxford, Mississippi. The stability of selected samples at low antecedent water contents was inversely related to both the rate and magnitude of water change in the sample. The influence of the rate of water change was evaluated by saturating the samples at varying rates immediately before the standardized hydraulic test. The influence of the magnitude of water change was evaluated by subjecting samples at low antecedent water content to hydraulic tests of varying time of erosion, temperature, and sediment concentration of the eroding water. Decreased temperature of the eroding water, shorter time of erosion, and increased sediment concentration reduced the amount of water change in the sample and reduced the rate and amount of material eroded. (SWC 1-bE4)

Hypotheses were developed and partially confirmed at the USDA Sedimentation Laboratory, Oxford, Mississippi, to explain the several mechanisms responsible for stability and resistance to erosion in cohesive soils. The concept involves two classes of bonding mechanisms: (1) Those that are most powerful for dry soil and decrease in effectiveness as moisture content increases; and (2) the one or more influences that increase in effectiveness as soil moisture content increases. The total resistance is then the sum of the several resisting forces and is generally, but not always, at a minimum at intermediate soil moisture values. Cohesive forces that are associated with increasing moisture content generally require aging of the moist material for full development. The extent of the cohesion and resistance to erosion increases as the moisture content increases during the aging period. At low moisture content, stability is achieved by other kinds of bonding mechanisms. Saturation of the test material immediately before the erosive event destroyed the low-moisture type of bonding forces and--in the absence of aging--produced little stability that might have been acquired with wet-aging. The saturated soils were highly erodible for the low moisture conditions during aging, thereby confirming at least a part of the hypothesis. (SWC 1-bE4)

E. Valley Sedimentation Rates and Distribution

Resurveys by the USDA Sedimentation Laboratory, in Toby Tubby and Hurricane Creek Valleys near Oxford, Mississippi, and in the Whitewater River Valley, southeastern Minnesota, indicate a considerable reduction in the rates of sedimentation since 1940. These changes are presumably due principally to reforestation and soil conservation programs, including the construction of many small reservoirs and farm ponds in the Mississippi area. However, possible influence of variations in precipitation and runoff have not yet been evaluated. Despite the reduction in rates, the general pattern

of sediment distribution in both the Mississippi and Minnesota valleys has continued to be about the same as was indicated by soil borings made 25-30 years ago. The thickest floodplain deposits and greatest accumulations of sediment have continued to be in the upper parts of the valleys, and on local alluvial fans and "valley plug" areas. This tendency for upstream and localized sediment concentration reduces rates of silting in downstream reservoirs and localizes areas where agricultural damage from sedimentation might be alleviated by protection or reclamation works. (SWC 1-bE2)

Resurveys by the USDA Sedimentation Laboratory in valleys of the White River, Minnesota, show a general tendency for streambed aggradation to occur at about the same rate as overbank floodplain aggradation. This relationship had not previously been determinable from sedimentation data based chiefly on soil borings. In northern Mississippi valleys there is some indication of a similar tendency, but with much more variability between stream channel and floodplain aggradation. This variability may be related to local ditching projects. (SWC 1-bE2)

F. Radiocarbon Dating of Sediments

At the USDA Sedimentation Laboratory, Oxford, Mississippi, the chemical equipment was revised to reduce the time required in processing radiocarbon samples and to eliminate hazards inherent in the original procedure. Emphasis was also placed on the analysis of peat from the Florida Everglades to provide an absolute chronology of the peat formation and development. Dating indicates the basal peat was formed during late Hypsithermal time (approximately 4,300 years ago), when the rising level of the sea slowed internal drainage from the Everglades basin, which caused a rise in the water table. Subsequently, the peat profile developed to a depth of almost 12 feet at a more or less constant rate of 0.0033 foot per year. This finding confirms earlier investigations, and emphasizes that the value of plowing under cover crops to prolong the life of such organic soils is highly questionable. Since the sawgrass peat accumulated at an average rate of 1 foot in 350 years under conditions that were presumably optimum for soil formation, and an average of only about 7 years was required for the same amount of soil to be lost by oxidation after drainage, then, obviously, the value of cover crops for conservation of these soils is trivial. At present, well-regulated water tables offer the best means of minimizing subsidence of peat and muck lands. (SWC 1-bE4)

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AREA 2: HYDROLOGY AND WATER RESOURCES RELATED TO AGRICULTURAL WATERSHEDS

Problem: An insight into the operation of the hydrologic cycle in agricultural watersheds is one of the essential segments of knowledge required for successful development, management, and utilization of the Nation's soil and water resources.

There are nearly 12,000 watersheds in the country in the size category commonly encompassed in developments under the Watershed Protection and Flood Prevention Act, the Small Reclamation Projects Act, and similar programs. About 8,300 of these watersheds need project action for development of flood prevention systems, water supply, public recreation areas, and irrigation and drainage enterprises. In addition, it will be necessary to evaluate the hydrologic performance of all these watersheds in connection with programs of comprehensive river basin planning now in progress and projected for the future.

Research-derived procedures for estimating floodflows, water yields, hydrograph shapes, base flow, and ground water accretions in relation to the use and treatment of watershed lands in the various geo-climatic regions of the country are an urgent need. Research on relations between improvement works in upstream tributaries and floodflows and water yields downstream along the principal tributaries and the main stems of major rivers is also a conspicuous need.

This research seeks new knowledge of hydrologic processes in agricultural watersheds. From it are derived prediction equations and criteria for the more efficient design of watershed programs and utilization of water resources.

USDA AND COOPERATIVE PROGRAM

The Division has a continuing long-term program involving engineers, geologists, meteorologists, soil scientists, ecologists, and statisticians in both basic and applied research on the hydrology of agricultural watersheds. The primary purpose of this research is to provide hydrologic guidelines for the formulation of an adequate system of interrelated structural developments and associated land treatment measures for the best use or combination of uses of land water resources within upstream watersheds and the river basins of which they are tributary.

The scientific effort directed to this area of research totals 39.2 professional man-years. Of this number, 6.9 are devoted to studies of precipitation patterns; 7.7 to soil moisture accretion and depletion; 2.4 to ground water accretion, movement and basin recharge; 4.1 to

aquifer-streamflow relationships; 11.1 to water yield and water supply and quality; and 7.0 to floodflows and storm runoff.

PROGRAM OF STATE EXPERIMENT STATIONS

A total of 40 scientific man-years is devoted to this area of research.

PROGRESS -- USDA AND COOPERATIVE PROGRAMS

A. Precipitation Patterns

1. Precipitation amounts. A relation of precipitation to elevation was developed on Sleepers River Experimental Watershed near Danville, Vermont, without regard to local gage exposure or gage location across the valleys. Precipitation was shown to increase significantly between elevations of 500 and 2,500 feet -- the increase being from 15.5 to 26.0 inches for the dormant season (October-April) and from 13.0 to 20.0 inches for the growing season (May-September). The reason for the smaller percentage of increase for the growing-season precipitation is attributed to the more randomly distributed summer thunderstorms in contrast to the large-area, generalized storms of the dormant season. (SWC 2-a1)

Rainfall data for 15 storms from each of 15 watersheds with a total of 400 raingages were analyzed in the Hydrograph Laboratory, Beltsville, Maryland, to obtain relationships fundamental to spacing of raingages for hydrologic investigations. The product-moment correlation coefficient (r) was computed for each combination of two gages in a watershed. Isocorrelation lines around a key gage in each watershed generally exhibit a nonisotropic pattern. The size and shape of area evolved by the r = 0.9 isoline differ around each key gage. A relationship was developed for obtaining the distance between raingages for an arbitrary standard (r = 0.9) as a function of two readily available climatic parameters, viz., 2-year, 1-hour, and 2-year, 24-hour rainfall. This generalized relationship may be considered useful as a first approximation to raingage spacing. The anisotropic characteristics of the isocorrelation lines around a key gage demonstrate that reliability of rainfall estimation at an ungaged point cannot be equated with gage density alone. Consideration must also be given to direction of gage distribution. Negative correlations obtained at Walnut Gulch, Arizona, are a result of the isolated mesoscale storm systems which produce the rainfalls. Analyses thus far have yielded a first approximation to a quantitative relationship between raingage spacing and the macroclimate. Networks designed for r = 0.9 generally should provide a good estimate of the volume of a storm but not of its spatial distribution. (SWC 2-aD1)

At Coshocton, Ohio, a comparison was made of rainfall amounts measured by recording raingages and by three 1/500-acre weighing lysimeters. The relation between lysimeter and gage catch was different at the three sites. Whether the differences were due to changes in lysimeter performance at the three sites for some unknown reason, to changes in raingage performance due to exposure or other factors, or to changes in both lysimeter and raingage performance is a moot point. The ratios of lysimeter to gage catch were 1.07, 1.04, and 1.05 at the Y101, Y102, and Y103 sites, respectively. From May through August, the ratio of lysimeter to gage catch was low, averaging 1.01. In March-April and September-October, the average ratio was 1.07, whereas from November through February the average ratio was 1.11. (SWC 2-c1)

Sunken gages with orifices within 2 inches of the ground surface were used to measure "true" rainfall at Boise, Idaho. The sunken gages caught 10 percent more rain than unshielded gages and 6 percent more than shielded gages when the orifices of the gages were 48 inches above the ground surface. Wind reduced the storm catch of rainfall for both shielded and unshielded gages by about 0.003 inch for each 1 mile per hour of maximum 5-minute windspeed. (SWC 2-f2)

The average annual precipitation on Walnut Gulch Experimental Watershed, Tombstone, Arizona, was 11.5 inches for the 1954-65 period, and 10.5 inches on the Alamogordo Creek Experimental Watershed, Santa Rosa, New Mexico, for the 1956-65 period. These amounts are substantially below the long-time averages reported by the nearest respective Weather Bureau stations. The differences are mainly in the winter rainfall, which has been relatively short in both vicinities in the last decade. Rains during the 1965-66 winter on Walnut Gulch were unusual, however, with five times the normal amount falling in December. Slight winter runoff was measured, for the first time, from small unit-source watersheds (fewer than 100 acres). No runoff occurred from the larger watersheds under measurement (0.8 to 58 square miles). (SWC 2-g1)

In 1965, summer rainfall on the Walnut Gulch Experimental Watershed, Tombstone, Arizona, was characterized by numerous thunderstorms in the vicinity, but few significant runoff-producing rains on the watershed. A persistent flow of moist air from the Gulf of Mexico contributed to convective rains over some part of the watershed on all but two days in a 3-week period in July. However, intense rains were of short duration, on small scattered areas, or were centered outside the watershed. On two occasions, heavy rains were recorded by gages less than a mile outside the watershed when only light-to-moderate rainfall was recorded within. This typifies summer thunderstorm patterns in intermountain areas of the Southwest. (SWC 2-g1)

Since installation of the reconnaissance recording raingage network in 1962 near Tehachapi, in eastern California, in cooperation with and operated by the Tehachapi Soil Conservation District, only about 20% of the total precipitation recorded has been from summer and fall convective thunderstorms. However, average 5-minute intensities in those storms have averaged about 5 times the intensities in frontal winter storms of corresponding durations. No severe convective storms have so far been recorded, by comparison with those known to occur occasionally in this locality. (SWC 2-g1)

Success in the use of computer models for predicting the runoff and net water yield of watersheds is dependent, first, upon a proper modeling of the precipitation input. Data from this research indicate complex patterns of both temporal and spatial variation of rainfall, within even rather small watersheds. The variations are evidently both random and systematic. This type of research needs to be pursued much further, to predict the precipitation variations to be expected. Consideration of varied rainfall probabilities within a general climatic region, and even within the confines of a given watershed becomes most important in evaluating proposed land-use, water resource development, flood control and watershed protection plans. (SWC 2-g1)

2. Rainfall intensity-duration. A storm with unusually high rainfall intensities occurred in July on Powells Creek Watershed, which is being studied from headquarters at Blacksburg, Virginia. The rainfall totaled 3.8 inches for a duration of 1.5 hours. In comparing the storm intensities with the maximum expected intensities at nearby Lynchburg, Virginia, as estimated in U. S. Weather Bureau Technical Paper No. 25, the 30-minute value of 4.70 inches per hour has an expected recurrence of once in 50 years and the 1-hour amount of 3.44 inches, an expected recurrence of once in 100 years. (SWC 2-a1)

At Ft. Lauderdale, Florida, analyses of 30 high-intensity rainfall events on two experimental watersheds (areas of approximately 100 square miles and 78 square miles) showed no significant differences in storm time-distribution patterns for the two watersheds. Rainfall intensity for most long-duration storms (12 or more hours) was greatest during the second half of the rainfall period, and the graph most closely resembled the SCS "C"-type distribution curve. However, rainfall intensity for most short-duration storms was greatest during the first half of the rainfall period, and the graph most closely resembled the SCS "B" distribution curve. These analyses of storm-rainfall characteristics are valuable for estimating the hydrologic design of channels and structures for water control. However, caution should be exercised in predicting areal rainfall from point rainfall measurements. The records analyzed revealed that one 50-year, 24-hour storm and four 10-year, 24-hour storms occurred at some place in the 100-square-mile watershed during the 13.5 years of record. Thus, it seems wise when designing water-control structures to consider the likelihood of excessive amounts of rainfall occurring on

a large watershed more often than is predicated for a geographical point. (SWC 2-b2)

3. Rainfall depth-area relations. The analyses at Ft. Lauderdale, Florida, described in the preceding section, also showed that storm depth-area relations tended to be a straight line when plotted on semilog paper. That is, the logarithm of areal-rainfall depth (expressed as percent of maximum-point rainfall) is apparently linearly related to area. This is an important finding that can be used to extrapolate results to larger watersheds. Correlation analyses showed the prediction equations for the 100-square-mile coastal watershed (Fla. W-1) to be:

$$Y = 10^{(2.0012 - 0.001161 X)} \quad \text{for storms longer than 12 hours}$$

$$Y = 10^{(1.9969 - 0.002773 X)} \quad \text{for storms less than 12 hours}$$

and for the 78-square-mile inland watershed (Fla. W-2) to be:

$$Y = 10^{(2.0075 - 0.000896 X)} \quad \text{for storms longer than 12 hours}$$

$$Y = 10^{(2.0018 - 0.002952 X)} \quad \text{for storms less than 12 hours}$$

where Y is rainfall depth expressed as percent of maximum-point rainfall and X is watershed area in square miles. Standard errors of rainfall depth (in logarithmic terms of percent maximum-point rainfall) for the Fla. W-1 data were 0.0208 for long storms, and 0.0422 for short storms. Standard errors for Fla. W-2 data were 0.0168 and 0.0606 for the long and short storms, respectively. High-intensity rains lasting fewer than 12 hours show similar depth-area relations for both watersheds. Apparently, depth-area relations for the shorter storms are essentially the same for coastal and inland areas. A greater slope of the depth-area-regression line for storms longer than 12 hours for the Fla. W-1 watershed than for the Fla. W-2 watershed indicates a difference in areal coverage between coastal and inland storms of long duration. (SWC 2-b2)

4. Orographic influences. Studies on the Reynolds Creek Experimental Watershed, Boise, Idaho, of the linear relation between rainfall intensity and the logarithm of the proportion of annual rainfall falling at that intensity, revealed that the coefficients in this relation obtained by least squares regression fitting were stable for four separate 900-foot elevation classes when tested by covariance. This suggests that data from accessible valley stations can be used to estimate the relative frequency of high-intensity rains throughout an area of appreciable range in elevations. (SWC 2-f2)

The reconnaissance recording raingage network near Tehachapi, in eastern California, provides a comparison of rainfall at varying elevations between 4000 and 7000 feet. Very consistently, rainfall recorded at higher elevations has exceeded that recorded by the Weather Bureau

gage in the valley at Tehachapi by from 100 to 300 percent. The increase rate in 1964-65 averaged about 4.2 inches per 1000 feet of elevation in the 4000- to 7000-foot elevation range. The 1964-65 records also indicated that precipitation was substantially greater on slopes facing south and west than on those facing north and east. (SWC 2-g1)

A vectopluviometer on a level site, near the coast at Lompoc, California measured 15 storms in the winter of 1964-65, totaling 13.1 inches. Four storms exceeded 1.0 inch and contributed 63 percent of this total. Two storms, exceeding 2.0 inches, contributed 23 percent. The horizontal mean directions of fall of all storms exceeding 0.25 inch were confined within an azimuth range of about 90 to 270° (from north), and storms exceeding 1.0 inch were more closely confined within about 130 to 200° azimuth. More notable is the finding that the vertical mean directions of fall of all rain in storms exceeding 0.25 inch were within the sector 17 to 66° from horizontal, and for storms exceeding 0.50 inch,it was between 43 and 66°. Again, as in the preceding two years of this study, it appears that the total rainfall input to a particular land area within a watershed (in this climatic region) may depend considerably on the steepness and aspect of its slope. (SWC 2-g1)

5. Snow depths. A snow pillow for measuring snow water equivalent, first investigated as to practicability by the University of Idaho under an ARS research contract, was used for snow measurements on Sleepers River Experimental Watershed near Danville, Vermont. The seasonal performance of a 12-foot-diameter snow pillow was compared with data from a recording precipitation gage and from snow course measurements. The snow pillow measurements were within about 0.02 inch of the other measurements. The response of the snow pillow to changes in the snowpack was immediate. The snow pillow performed very well in spite of the Eastern conditions of rains, thick ice lenses, and shallow snowpack. It is considered to have promise as a research tool in snowpack studies. (SWC 2-a1)

Snowpack development in nonforested, mountainous areas of marginal snow accumulation as observed on the Reynolds Creek Experimental Watershed, Boise, Idaho, is primarily a function of landform, modified by the effects of vegetation. The variability of the snow water equivalent distribution progressively increases throughout the winter until a stable, nonuniform distribution is reached in late winter. The nonuniform distribution results from the entrainment of snow in the windstream in areas of low roughness and/or convergent flow, with subsequent deposition in areas of high roughness or divergent flow. (SWC 2-f3)

6. Snowmelt. Cooperative studies of the physics of metamorphosis of the snowpack and the causative factors that result in runoff from the snowpack were initiated with the U. S. Weather Bureau on the Sleepers River Experimental Research Watershed, Danville, Vermont. Extensive microclimatological instrumentation to study point snowmelt by a total energy budget approach will be established. The study will lead to

improved methods for evaluating and predicting the effect of snowmelt runoff during spring floods in the Connecticut River Basin. (SWC 2-a1)

Weight records from snow-covered, 1/500-acre lysimeters provided a means for evaluating evaporation from snow at Coshocton, Ohio. Windy days were omitted because drifting would have been a complicating factor. During 2 years, evaporation from snow on clear, calm days averaged 0.02 inch per day in January and February. High values (0.05 inch) occurred on February 5, 1965, with an air temperature of 40 degrees and a relative humidity of 51 percent. (SWC 2-27(c6))

B. Soil Moisture Accretion and Depletion

1. Infiltration. Since runoff volume under the flood hydrograph usually constitutes only 5 to 15 percent of the precipitation volume, an investigation is being made at Danville, Vermont, to determine just where the storm runoff comes from. It was hypothesized that only those parts of the watershed very close to the streams contribute to storm runoff and that the "wet" soils would contribute much more than the "dry" soils. In a test on a 17.2-acre incremental area on watershed W-2, it was found that 1.8 acres of "wet" soils contributed 87 percent of the runoff for one storm of 1.50 inches total rainfall. No overland flow was observed on the 15.4 acres of "dry" soils during this storm, and it is believed that 80 to nearly 100 percent of the rainfall could be stored in the "dry" soils during such a storm. (SWC 2-a2)

The ARS survey to characterize infiltration and storage capacities of selected soils on approximately 200 ARS plots and experimental watersheds was essentially completed this year. Data from this survey will be used in a variety of ways centered around the evaluation of infiltration, soil moisture storage, and release of water in the development and testing of techniques for predicting these components of a watershed model. (SWC 2-aD1)

A practical formula was developed in the Hydrograph Laboratory for predicting infiltration during unsteady rainfall based on soil characteristics available from soil surveys of the Soil Conservation Service. Current techniques assume continuous ponding of water on the soil surface, a condition rarely maintained on watersheds, and result in estimates of infiltration capacities which diminish with time regardless of rainfall. The new equation estimates the infiltration capacity as depleting with exhaustion of the storage potential in the soil. Exhaustion is at the rate of rainfall or at the capacity rate of infiltration, whichever is limiting. Infiltration recovery during hours or days of no rainfall is computed as a recovery of storage potential in the soil by downward seepage or by evapotranspiration. By this technique, variations of rainfall intensities and amounts are systematically considered in runoff computations. (SWC 2-aD1)

A tensiometer system that has a small lag time was designed for use in subsurface storm flow studies at the North Appalachian Experimental Watershed, Coshocton, Ohio. In this system mercury manometer-connected tensiometers are used in soils of high permeability when at high moisture contents, and electrical pressure transducer-connected tensiometers are used in soils of low permeability at any moisture content. Readings on electrical transducer tensiometers in Keene subsoil during the sprinkler application of water to plots showed the development of an equipotential system in which lateral flow could occur. (SWC 2-c2)

2. Soil moisture balance. Further attempts were made in 1965 at Oxford, Mississippi, to establish soil-moisture-depletion curves under controlled conditions at selected sites, using nuclear soil-moisture probes. Two probes, a standard Troxler probe with a 3-mc. gamma ray source and a probe with a 100-mc. source were used. Generally the 100-mc. probe indicated the more normal moisture-depletion pattern expected. However, plottings of soil moisture versus time showed considerable scatter, which suggests that factors not being measured are affecting moisture depletion at the study sites. In connection with the nuclear soil-moisture measurements, it was found that calibration curves can be obtained for Nuclear-Chicago neutron probes by determining the count-rate moisture percentage for two points only. One of these points is a (infinite) water reading, and the other is a reading for a moist soil of known moisture content. The line connecting the two points will serve as a first approximation of a calibration curve. A similar response was not obtained for Troxler neutron probes.
(SWC 2-b4)

A dual probe, utilizing cesium-137 as the gamma-ray source and operated with a scintillation-differential spectrometer, has been developed and tested for field use at the USDA Sedimentation Laboratory, Oxford, Mississippi. The system is capable of measuring soil-moisture changes, as a function of soil density, in soil layers of 1-inch vertical thickness with an error of as little as 0.5 percent by volume. (SWC 2-b4)

A 27-year study of soil moisture data on meadowland of silt loam soil at Coshocton, Ohio, resulted in the development of a single moisture depletion curve for the growing season for the 0- to 7-inch depth of both Keene and Muskingum soils. This curve was applied successfully in a moisture bookkeeping method to predict daily soil moisture values for 3 years. The differences between predicted and observed values were less than 0.15 inch for more than 75 percent of the observations. Soil moisture in the 0- to 7-inch depth relates strongly to the amount of storm rainfall retained and the amount of flood runoff. (SWC 2-27(c6))

The influence of depth of soil moisture observations on crop consumptive use evaluations is revealed by studies made at Coshocton, Ohio. Growing season water-use values derived from observations in the 0- to 72-inch depth. The latter are near the true values; they differed from

those of the 96-inch-deep weighing lysimeter by less than 7 percent. Water-use values are needed for the design of irrigation systems, for determining efficiency of water use, and for predicting watershed yield of water. (SWC 2-27(c6))

In a relatively cool marine climate, near the coast at Lompoc, California, the 1964-65 rainfall was 15 inches, and the average evapotranspiration from 10 soil moisture measurement stations under native vegetation (grass and brush) in the lower Santa Ynez River Watershed was 14 inches. The net accrual of 1 inch in soil moisture storage partially replenished a 2.4-inch overdraft in the preceding year, when rainfall was 8.1 inches. An 86% increase in the rainfall resulted in a 32% increase in water consumption by the native vegetation. Evapotranspiration was essentially the same from grass and brush sites. A bare-ground site lost about 8 inches less water than the vegetated sites. (SWC 2-g3)

3. Vegetative cover. For a 19.2-acre single-cover, unit-source watershed at Watkinsville, Georgia, only 36.1 inches of rainfall and 0.1 inch of runoff were recorded in 1965. This follows the 72.4 inches of rainfall and 15.7 inches of runoff recorded in 1964. A gradual increase in runoff has been experienced since Coastal bermudagrass was planted in 1959. This increase is probably due to increased compaction resulting from increased grazing rates by livestock. Cow-days grazing increased from 4,350 in 1960 to more than 10,000 per year during the 1961-64 period. In 1965 this rate decreased to 5,470, but 23.9 tons of Coastal bermudagrass hay were cut and removed from the watershed. (SWC 2-b3)

Data obtained at the Cottonwood Field Station, Newell, South Dakota, show that the average total cover of plant material per acre on each of the three groups of watersheds (lightly, moderately, and heavily grazed) was approximately 200 pounds greater in 1965 than in 1964. Approximately 3/4 ton more mulch or litter per acre was observed on the lightly grazed watersheds than on those that were heavily grazed. Although the 1965 annual precipitation was greater than that received in 1963 or 1964, runoff water yield from the heavily and moderately grazed watersheds was lower than the water yield in 1963 or 1964. One reason for the lower water yield was that storms in 1965 were of lower intensity. A correlation coefficient ($r = 0.888$) was obtained when comparing runoff to vegetation litter under each intensity of grazing. (SWC 2-d1)

Studies near Newell, South Dakota, to evaluate the relative runoff-producing potential of principal range sites of western South Dakota show that for one of the mixed-range site watersheds, runoff was 0.8 inch, or 3.9 percent, of the total precipitation received in 1965. Using total values of runoff for 3 years, a comparison of runoff from panspot range sites and sandy range sites showed that panspots yielded more than nine times as much runoff water as did the sandy range sites. Also, average values in inches of runoff per 100 pounds of total cover of plant material were 0.007 inch for the sandy range sites as compared with 0.055 inch for the panspots sites. (SWC 2-d1)

A study of seeding cropland to native prairie grasses at the Central Great Plains Experimental Watershed near Hastings, Nebraska, shows that sufficient cover is produced in 4 years to control surface runoff and soil erosion. Results obtained in 1965, which confirm findings reported last year, show that new seedings on two watersheds produced an average of 3.0 inches runoff, and old native grass meadow on another watershed produced 3.4 inches runoff. By comparison, six cultivated watersheds produced an average of 9.2 inches of runoff. The average slope of these watersheds is 4 percent, and the soils are in the Hastings and Holdrege soil groups with a silty to silty clay loam texture. (SWC 2-d1)

At Boise, Idaho, on the Reynolds Creek Experimental Watershed, sagebrush crowns are elliptical, with the ratio of the semiminor to the semimajor axis of 0.73. This departure from circularity introduces an overestimation of canopy cover by 10 percent when using the variable plot technique. The horizontal arrangement of sagebrush leaves is quite uniform, with the leaves occupying 33 percent, on the average, of the vertical projection of the canopy area. (SWC 2-f3)

Vegetative cover improvement tests have continued on a number of plots on the Walnut Gulch Experimental Watershed, Tombstone, Arizona, including tests of brush removal, surface pitting, seeding, and fertilization in a predominantly brush-covered area; and supplemental moisture and fertilization applications on predominantly grass plots. Fertilizing and seeding test plots were also established on the Alamogordo Creek Experimental Watershed, Santa Rosa, New Mexico, in 1965. Runoff and erosion measurements are made from all plots, and their soil moisture regimes studied. In the second year after fertilization, the forage weights of some of the more important perennial grasses are showing statistically significant increases on the Walnut Gulch grass plots, with strong trends also indicated for increasing basal area and crown spread. There is no indicated change in species composition as a result of fertilization. However, maintenance of a moderate soil moisture level by sprinkling has significantly increased forage weight and basal area and crown spread of total species and of perennial grasses. (SWC 2-g2)

Pitting of grass-covered study plots on a clay-loam soil in the Alamogordo Creek Experimental Watershed, Santa Rosa, New Mexico, in the spring of 1965, resulted in dramatic reduction of rain-site runoff. On the other hand, pits on brush-covered, gravelly sandy loam plots on the Walnut Gulch Experimental Watershed, Tombstone, Arizona, have virtually disappeared after two seasons, except where there is considerable vegetation. No effect of the pits on runoff was discernible. (SWC 2-g3)

4. Watershed evapotranspiration. On an annual basis the measured evapotranspiration (precipitation minus runoff) shows close agreement with the potential evapotranspiration for six watersheds at Danville, Vermont, for four years of record. The potential evapotranspiration is

taken to be equal to seven-tenths of the annual pan evaporation. This same close comparison of measured and potential evapotranspiration has been observed at the U. S. Forest Service Hubbard Brook Forest Experiment Station in New Hampshire. A cooperative study on this subject has been initiated by the ARS Danville project and the USFS Hubbard Brook project. The potential slightly overestimates the measured evapotranspiration, indicating some bias. This interpretation that the actual and potential evapotranspiration are about equal seems valid, since there is sufficient soil moisture throughout the growing season. Even during the very dry summer of 1963, the soil moisture was between 12 and 34 percent by volume in the top 24 inches of soil. (SWC 2-a2)

A review of evaporation studies at Ft. Lauderdale, Florida, made in connection with investigations to find methods of determining the water balance of small agricultural watersheds in peninsular Florida from climatic data, indicated that the values for potential evapotranspiration obtained from evapotranspirometers are generally more consistent, and probably offer a better index of evaporativity, than U. S. Weather Bureau evaporation pans. Equations developed earlier for computing evaporativity from evapotranspirometers using air temperature and solar radiation were adapted to fit other climatic regions where daytime humidity is known. It was found that, for practical engineering use, estimates of monthly potential evapotranspiration can be made for the continental United States by grouping relative humidities into four major divisions as follows:

(1) where R. H. is greater than 60%;

$$E_t = (0.00820\ \overline{T}_a - 0.1900) \times Q_s/1{,}500$$

(2) where R. H. is between 50% and 60%;

$$E_t = (0.00878\ \overline{T}_a - 0.1938) \times Q_s/1{,}500$$

(3) where R. H. is between 40% and 50%;

$$E_t = (0.01067\ \overline{T}_a - 0.2256) \times Q_s/1{,}500$$

(4) where R. H. is less than 40%;

$$E_t = (0.0140\ \overline{T}_a - 0.3700) \times Q_s/1{,}500$$

in which R.H. is the average relative humidity, local-noon time for July, obtained from a map in the 1941 Yearbook of Agriculture; E_t is the potential evapotranspiration, in inches, for complete vegetative cover, where moisture supply is not limiting and the oasis or "clothesline" effect is minor; T_a is the average monthly temperature in degrees Fahrenheit; and Q_s is the monthly solar insolation, in langleys. (SWC 2-b1)

A study made to differentiate between soil evaporation and plant transpiration at Fort Lauderdale, Florida, using 12 evapotranspirometers with a constant 24-inch water table and replicated treatments of full sod cover, two-thirds sod cover, one-third sod cover, and no sod cover, showed a linear relationship between percent ground cover and evapotranspiration from Tifway bermudagrass. This relation may be expressed by the function,

$$Y = 44 + 0.56X$$

where Y is percentage of evapotranspiration from full sod coverage, and X is percent ground cover. The total evapotranspiration from the full sod cover in 1965 was 41.7 inches. The information obtained from these controlled experiments will be related to the percent ground cover of experimental watersheds to estimate potential watershed evaporation, and then compared with evaporation obtained from rainfall-minus-runoff water-balance computations. (SWC 2-b1)

C. Ground Water Accretion, Movement and Basin Recharge

1. Ground water movement. Geologic investigations at Danville, Vermont, have determined that the bedrock under the watershed is impermeable, and that there are no deep seepage accretions or losses. However, the upper parts of the bedrock are fractured, and considerable weathering has occurred. This rock near the surface is a saprolite and is so oriented that it could divert water from one small watershed to another one. This shallow transfer of water across watershed boundaries as defined from surface topography would have some effect on the water balance for a small watershed, but would have little effect on larger watersheds because such diversions would be compensating. (SWC 2-a2)

Studies were made on an experimental 19-acre group of controlled water table plots at the Everglades Experiment Station, Belle Glade, Florida, to characterize ground water movement in organic soil lying over a limestone substrata. At an estimated head of 0.5 foot, seepage losses to the surrounding area were about 1.0 inch per day. The seepage occurred through 4,100 feet of perimeter channel. Thus, ground-water pickup through these strata is computed to be approximately 2.3 c.f.s. per mile of channel for each foot of head. These estimates are useful for designing group-drainage projects in the upper Everglades agricultural area. (SWC 2-b4)

The continuing study of artesian pressure and inflow data on the research watershed near Vero Beach, Florida (Fla. W-1) has shown that increased use of artesian water in this area has caused an average annual head loss in pressure of 0.5 foot. The study further showed that annual usage of artesian water has increased by 10.5 inches since 1960. This tends to confirm last year's conclusion that if areawide piezometric levels continue to decline, it may be desirable for authorities

to impose restrictions in the Cape Kennedy area that limit well discharges to proven beneficial uses consistent with long-time aquifer recharge rates. (SWC 2-b4)

At Oxford, Mississippi, monthly measurements in selected observation wells continue to show only minor fluctuations in ground water, or piezometric, levels in Pigeon Roost Creek watershed. In spite of below-normal rainfall (about 20 percent during 4 of the last 5 years), the pressure elevations of the semiconfined water table have remained relatively constant. The principal water-bearing formation beneath the watershed is the Meridian sand. Even though total annual runoff has varied significantly during the period of record--since 1957--baseflow has remained relatively constant. This indicates the considerable influence of inflow from the Meridian formation, which is not readily affected by annual fluctuations in precipitation and infiltration. (SWC 2-b4)

Investigations of aquifer characteristics on the Reynolds Creek Experimental Watershed, Boise, Idaho, confirmed the supposition that the primary water movement in basalt occurs along contacts between lava flows, in fractures caused by cooling and deformation of the lava, and in gas vesicles where interconnected. Drawdown curves from pumping tests exhibit several prominent changes in shape as they intersect these different structural and textural zones, indicating wide ranges in permeabilities. The water levels rise higher and more rapidly in basalt aquifers than in sediments from recharge by precipitation. (SWC 2-f1)

2. Basin recharge. At Ft. Lauderdale, Florida, an analysis was made of the ground water table rises related to 84 rainfalls occurring on Upper Taylor Creek watershed (Fla. W-2). These rainfalls were 1-day events with no rain within 24 hours before or after the event, and water tables were within the range of 2.5 to 4.5 feet below ground surface. The average rise in water table was expressed by the relation: $Y = 0.817 X - 0.235$, where X is inches of rainfall and Y is feet of rise in water table. The correlation coefficient, r, was 0.787. This relation indicates that over the whole watershed, on the average, approximately one-third inch of rain is required before the water table starts to rise, and it rises thereafter at the rate of approximately 10 inches for each inch of rainfall. (SWC 2-b4)

Geologic investigations at the North Appalachian Experimental Watershed, Coshocton, Ohio, have established a relationship between occurrence of gravity springs and perched water. Extensively fractured rock strata overlying relatively impermeable geologic clay formations provide zones of ground water storage. Unusually strong springflows are found at the outcrop of clay strata having a geologic basin-type structure. Recharge of these underground basins from infiltrating and percolating storm rainfall is an important phase of the hydrologic cycle relating to usable water yield--the sustained flow from upland watersheds. (SWC 2-c5)

In the Edwards Plateau near Sonora, Texas, five reservoirs with a total of 21,440 acres of drainage area had 1,056 acre-feet of inflow during May 1965. Much (660 acre-feet) of this inflow was transmitted to ground water with only limited losses to evaporation. (SWC 2-e4)

The heavy rains and prolonged bankfull flow of the Washita River in September were sufficient to cause a temporary increase in ground water storage in narrow zones bordering the river in the study reach under investigation by the Southern Great Plains Watershed Research Center, Chickasha, Oklahoma. The annual fall-winter decrease in evapotranspiration caused minor increases in water levels in most wells. However, by the end of 1965, the levels in nearly all wells were again declining. The general trend of gradually declining ground water levels, which began about 1960, will probably be reversed only by a general increase in yearly precipitation. (SWC 2-e4)

In a study reach of channel in the Walnut Gulch Watershed in which pervious alluviums overlie a tight rock formation at 6- to 30-foot depths, a water balance study indicates that 80 percent of the water retained from transmission losses was consumed locally by direct evaporation from the streambed surface and evapotranspiration from its fringe of dense riparian vegetation. It is apparent from observation of such vegetation adjacent to ephemeral stream channels throughout the Southwest that much of the potential yield of semiarid watershed lands is consumed in this way. (SWC 2-g3)

At the Lompoc, California Field Station, total rainfall in the 1964-65 water year has been exceeded in only 3 of the 9 years of study. Nevertheless, percolation beyond the root zone depths of the native vegetation occurred on only a bare-soil plot. On the Arizona and New Mexico study watersheds there is probably never any direct rainfall recharge of ground water in the uplands. Any recharge of the regional watertable from the semiarid rangeland watersheds occurs in their alluvial valleys, from runoff losses in their channel systems. (SWC 2-g3)

Ground water observation wells in the valley near the outlet of the Walnut Gulch Watershed have in some years indicated mounding of the deep regional water table related to the surface runoff season. However, measurements in the past two years indicate this is not an annual phenomenon, and may not occur except in seasons when the surface flows are comparatively large and frequent. (SWC 2-g3)

D. Aquifer Streamflow Relations

1. Subsurface contributions to streamflow. Two of the ten watersheds being studied in Virginia for differences in hydrologic behavior were selected for geomorphic comparison because of extreme differences in runoff. Brush Creek, a 893-acre watershed located in the Blue Ridge Mountain physiographic region, has an annual precipitation of 38.2 inches

and an annual runoff of 19.8 inches. The 786-acre Crab Creek Watershed is located 11 miles away in the Appalachian ridges and valleys and has an annual precipitation of 34.6 inches and an annual runoff of 7.1 inches. The large differences in runoff are attributed to differences in soils and geology. The Brush Creek Watershed soils are derived mainly from gneiss and schists, whereas those of Crab Creek are developed from dolomitic limestones and shales. Brush Creek Watershed has greater land slopes, four times the drainage density, ten times the number of streams, and five times the total stream length of Crab Creek Watershed. (SWC 2-a2)

A long-term study comparing runoff from several Florida experimental watersheds of different sizes and at decidedly different states in drainage and agricultural development continued at Ft. Lauderdale, Florida. For the 50,000-acre Indian River Farms Watershed (Fla. W-1), which has a highly developed drainage and irrigation system, the long-term average runoff was 43 percent of the rainfall until 1959. After 1959, this rose to 55 percent, and a recent investigation disclosed that numerous additional artesian irrigation wells had been put into use. For the 63,000-acre Upper Taylor Creek Watershed (Fla. W-2), which until recently has had few water-control improvements for drainage and irrigation, the long-term average runoff has been 30 percent. The average water yield from the Indian River Farms Watershed has been approximately 28 inches as compared with 15 inches from Upper Taylor Creek Watershed. Since the rainfall is only 5 inches greater on the first watershed, and since most of the additional runoff occurs in the winter and spring months during periods of low rainfall, the increased ratio of runoff to rainfall on Indian River Farms watershed is attributed to artesian supply. (SWC 2-b1)

Flow from three of a total of about 30 hillside springs made up 55 percent of the year's base flow and 18 percent of the total streamflow from a 303-acre watershed at the North Appalachian Experimental Watershed, Coshocton, Ohio. Monthly values of measured springflow ranged from 12 percent of total flow in September to 39 percent in June. This represents a significant contribution from the rock aquifers. Measured springflow accounted for as much as 95 percent of computed base flow in February, near the peak of maximum ground water storage. (SWC 2-c5)

Measurements of ground water levels in the vicinity of earth dams near Chickasha, Oklahoma, indicate the need for additional instrumentation to determine the amount of water added to the ground-water flow by seepage from the reservoirs. Simple tests of chemical characteristics of the ground water show increase in dissolved solids in the ground water below the dams. (SWC 3-e2)

2. Channel transmission losses. To determine channel transmission losses in Pigeon Roost Creek Watershed, Oxford, Mississippi, measurements of moisture by nuclear methods in the top 15 feet of the channel bed were continued from June through December at a selected site in channel #4. Although the channel bed normally remains saturated for several months

annually, moisture measurements show available storage in the bed for sizeable quantities of runoff during the summer and fall months. Possible seepage losses of 25 inches of water per unit area of channel were indicated. Seepage losses over a period of time would, of course, depend on antecedent conditions at the beginning of runoff events and the distribution of runoff. (SWC 2-b4)

During the last 11 days of September 1965, maximum flows occurred at several of the gaging stations on the Washita River and tributaries being operated by the Southern Great Plains Watershed Research Center, Chickasha, Oklahoma. The main stem was out of bank between Anadarko and Chickasha, and Sugar Creek experienced the largest runoff since 1949. The surface flow during these 11 days between Anadarka and Chickasha disappeared into the channel and valley alluviums at the rate of about 36 acre-feet per mile per day. (SWC 2-e4)

There were no important runoff-producing storm events over the unit-source watersheds in the Lucky Hills area of the Walnut Gulch Experimental Watershed, Tombstone, Arizona, in the 1965 season. Early September rainstorms totaling around 2.3 inches resulted in relatively large flows from the predominantly grass-covered watersheds. However, the runoff per unit area was about 30 percent less from a 120-acre watershed than from 4.6 acres at its upper end. The difference is attributed to transmission losses in the alluvium in the intervening channel. (SWC 2-g2)

Inflow-outflow measurements for several reaches of the main channel system of the Walnut Gulch Watershed, and for several runoff events in the past summer, indicated infiltration rates of from 1.1 to 4.5 inches per hour into the sand-gravel bed materials. The transmission loss rates are positively related to the inflow rates of a given channel reach, and also to flow sequences which affect both the antecedent moisture content and the mechanical condition of the bed materials, particularly as the latter is affected by alternating deposition and scour of the relatively fine sediments and braiding by low flows. (SWC 2-g3)

E. Water Yield and Water Supply

1. Low flows. In a preliminary analysis of low flows at Danville, Vermont, the annual minimum volumes of flow were determined for 1, 2, 5, 14, 20, and 30 days for 2 subwatersheds of Sleepers River Experimental Watershed and for Switzer Creek, Cohocton, New York. When these minimum volumes of runoff are plotted against the time interval in days, the log-log plot appears to be a straight line for the data for each year of record. The minimum volumes of flow in inches per unit of area are very similar between watersheds regardless of watershed size. A precipitation index value was estimated for the watersheds at Danville, Vermont, by taking the sum of precipitation during the minimum flow volume interval and during the previous 30-day period and then deducting the runoff that would occur during these periods by using a recession constant of 0.9. When the

precipitation index values are plotted against the minimum flow volumes, there is considerable scatter in the points, but the number of days in the minimum flow volume do not seem to be important. These values could perhaps be refined by adjusting the results for the average temperature during the period in question and by taking a period longer than 30 days for the antecedent precipitation. (SWC 2-a2)

Previous studies at Ft. Lauderdale, Florida, indicated that the Hazen method of computing low-flow expectancies fitted the flow records of Florida streams better than the Gumbel method. During 1965 the low-flow data for Taylor Creek Experimental Watershed (W-2) in the Southern Florida Flatwoods Land Resource Area were analyzed by both methods. These studies confirmed that Hazen's frequency prediction curves fitted the low-flow data (7-, 14-, and 30-day) from this watershed more closely than did the Gumbel prediction curves. (SWC 2-b1)

2. Water yield. Investigations by the North Central Watershed Research Center, Columbia, Missouri, in the Iowa and Missouri Deep Loess Hills Land Resource Area, at Treynor, Iowa, showed that streamflow from a watershed with level terraces in corn was 13.07 inches in 1965, or only 0.8 inch less than that from an unterraced watershed. However, storm surface flow from terraced and unterraced watersheds was materially different, being 2.52 and 10.66 inches, respectively. Sustained flow was 10.55 inches for the terraced area and 3.26 inches for the unterraced watershed. Any increase in sustained streamflow in this area of 35 inches annual rainfall is generally of considerable value for water supply and dilution of pollution. (SWC 2-c4)

At Akron, Colorado, studies involving use of conservation benches for concentrating runoff from sloping land showed that fallowed contributing areas on 1 percent slopes yielded 1.9 inches of runoff in 1965. Runoff from fallowed slopes was twice that from slopes contour planted to sorghum. Contributing areas with slopes of 100, 200, and 300 feet long averaged 2.4, 2.0, and 1.6 inches of runoff, respectively. (SWC 2-d1)

Studies designed to divert and spread runoff onto an adjacent series of level benches at Akron, Colorado, continue to yield much useful data. In 1965, annual runoff from a 23.2-acre grassed watershed contributed 1.8 inches of extra moisture to three level benches, each 1.7 acres in size. Runoff from 577 acres of mixed-cover watersheds above the level pans averaged 0.65 inch or 2.9 percent of rainfall in 1965. For individual watersheds, runoff varied from 0.45 inch from a 357-acre watershed to 1.77 inches from an 18.4-acre watershed. Of the 380 acre-inches of runoff measured in the level pan system, 330 acre-inches were stored in the pan area. Each pan received an average of 10.0 inches of supplemental water during the growing season. (SWC 2-d1)

At the reservoir sites in Lowrey Draw near Sonora, Texas, the maximum runoff into the reservoir at Site 12 was only 1.39 inches from 7.73 inches

of rain in May 1965. At the other three sites, with more than 6 inches of rainfall, the difference between rainfall and runoff ranged from 5.91 inches to 6.35 inches. Apparently, during storm periods of the type experienced in May 1965, 6 inches or more of rainfall will enter the soil profile and not appear as storm runoff. (SWC 2-e3)

In the Blacklands of Texas near Riesel, a method of comparing runoff volumes from a watershed with two treatments for the same period of time has been developed. Another watershed with little change in land use or treatment is used as a base. The watershed under study has a comparable use for a relatively short period, after which changes are made. From rainfall and runoff records for the base watershed and for the watershed under study, both treatments can be compared for the same period of record. This procedure is being effectively used with a base watershed of 176 acres, and comparisons are made for watersheds ranging in size from 16 to 1,100 acres and at distances as great as 4 miles. (SWC 2-e3)

At Moscow, Idaho, analysis of the 1932-47 runoff data from the South Fork Palouse River Project gave little indication of decreased water yield with area for small agricultural watersheds. Average annual water yield was about the same from a few acres at Pullman, Washington, as from several hundred square miles above a point farther downstream. Surveys of 437 stock ponds constructed during 1940-63 in Latah County, Idaho, indicate that most small watersheds yield from 1 to 5 inches of runoff annually. (SWC 2-f4)

A 0.9-square-mile subwatershed to Walnut Gulch, Tombstone, Arizona, which is predominantly brush covered, was contour ripped in the fall of 1964 to evaluate the practice's potential for improving the grass stand and its possible effect on net water yield. Increased growth of grass adjacent to the furrows indicated that an increased amount of water was being retained on the upland in small storms. To reduce the net runoff, however, this retention would have to exceed transmission losses occurring in the rather broad sand-gravel channel that extends for a considerable distance upstream from the watershed outlet. No storms in the past season were adequate to indicate net runoff reduction from this watershed treatment. (SWC 2-g3)

3. Water supply. A system installed to drain hillside seeps effectively removed excess water harmful to tillage operations at the North Appalachian Experimental Watershed, Coshocton, Ohio. But more than this, the system can be made to provide usable water needed in downstream areas. A single drain tube, set on a geologic clay near its outcrop to intercept seepage water, delivered as much as 33 cubic feet per hour to a gaging station. At another site, the peak rate was 80 cubic feet per hour. (SWC 2-c5)

At Newell, South Dakota, studies on the collection and storage of rainfall runoff for domestic and stock water supply showed that for 2 successive years, more than 90 percent of the annual stored runoff was lost by evaporation and seepage. (SWC 2-d1)

F. Floodflows and Storm Runoff

1. Rates of discharge. Estimates of flow retardance are essential to flood routing in natural channels and to the design of engineering works. The need is particularly great to reformulate flow equations to recognize changes in retardance as depth of flow increases. The equations of Manning and Chezy were tested in the Hydrograph Laboratory, Beltsville, Maryland, using published data from flows in laboratory flumes with rectangular cross sections involving a range in size, roughness, bed slope and flow conditions. Both equations worked extremely well in smooth, straight, and rectangular flumes for steady, uniform flow--the conditions for which they were originally derived. High correlation coefficients were obtained for spatially varied flows, but a break in the slope of the plotted relationships indicated appreciably lower velocities below an associated depth, which varied with channel roughness. Recognition of this break greatly improved the predictability of velocity. A premise now being worked on through contract research assumes two areas of flow: (1) A sieve-type flow through or between substances offering resistance; and (2) a shear-type flow of water upon water in that portion of the flow section lying above the projections that constitute channel roughness. Impenetrable objects such as boulders will be considered as contractions and not included in this study. (SWC 2-aD1)

Investigations by the North Central Watershed Research Center, Columbia, Missouri, on watersheds representative of the Iowa and Missouri Deep Loess Hills Land Resource Area, showed that storm peak flows from a 150-acre watershed in the first year after terracing were less than one-tenth of those from an unterraced watershed, and storm flow volumes were two-fifths. Initial research results showed that level terraced cornland was as effective as grassland in reducing storm flow. (SWC 2-c3)

At Hastings, Nebraska, rainfall for 1965 was the highest on record for the period 1939 to 1965. However, storm runoff from six watersheds farmed with minimum tillage practices was not as high during 1965 as in some of the previous years of above-average rainfall. This was apparently due to improved tilth and increased accumulation of organic matter in the surface. (SWC 2-d2)

The record storms of December 1964 and January 1965 caused severe erosion in the 93.5-square-mile Reynolds Creek Experimental Watershed, Boise, Idaho. A 5-hour storm averaging 1.40 inches, following a storm of 0.8 inch which occurred about 12 hours earlier, produced a peak discharge of 3,800 c.f.s. or about 64 c.f.s. per square mile. The 1-hour maximum storm intensity averaged about 0.5 inch per hour. Suspended sediment loads at discharges of about 700 c.f.s. during the January 28-29, 1965 storm ranged from 14,000 to 20,000 p.p.m. (SWC 2-f3)

2. Dynamics of channel flow.

A system was developed in the Hydrograph Laboratory, Beltsville, Md., for determining the proper number of routings to be used in each reach when routing streamflow by storage-outflow relationships. The number of routings (N) is based on the rate of rise of the inflow hydrograph (I') and the slope of the storage-outflow relationship (K) by the equation: $N = 10\ K/I$. Observed inflows to the mainstem from gaged tributaries at Fennimore, Wisconsin, were routed through channel storage computed from detailed channel geometry for comparison with recorded outflows downstream. The minimum number of reaches is fixed by point of entry of major tributaries. Best fit to the recorded outflow was obtained when the indicated storage in each of the fixed basic reaches was divided by N, as determined for each event and used in N sequential routings. This technique provides an objective approach as a substitute for the highly subjective estimates of travel time, erroneously used as a constant. (SWC 2-aD1)

3. Hydrograph synthesis. A number of small-area hydrographs have been published by ARS-SWC in USDA Misc. Pub. 945. Without additional information, a "rational" analysis of these hydrographs is difficult. In lieu of this, an asymmetric function with only one parameter was developed to compute a characteristic hydrograph shape. The function was written specifically for a dimensionless hydrograph as:

$$q/q_p = \text{EXP}\ (-nt)$$

where q_p is peak rate; T is $\ln(t/t_p) + 2(1/\sqrt{(t/t_p)} - 1)$; t_p is time to peak; ln is natural logarithm; EXP is base of natural logarithm; t is time and n is parameter. This function was fitted independently to the rising and falling sides of the hydrograph; thus, each hydrograph has two values of n associated with it. The actual fitting process was done on an IBM 1620 computer. An n value was selected on the basis of fit, i.e., a minimum value of the

$$\sum \left((q/q_p)_o - (q/q_p)_c \right)^2$$

where $(q/q_p)_o$ are observed ordinates and $(q/q_p)_c$ are calculated ordinates. (SWC 2-aD1)

A characteristic lag time was again demonstrated to be a highly significant determinant of the hydrograph geometry for watersheds of about 1 square mile or less, in a recent reanalysis of 26-year records from a study at Tucson, Arizona, of seven watersheds in the vicinities of Safford, Arizona, and Albuquerque, New Mexico. However, it is apparent that lag time is not directly applicable in predicting the hydrograph shape for larger watersheds in the Southwest for which the hydrograph shape is dominated by channel transmission phenomena. A study of the hydrographs of the Walnut Gulch Experimental Watershed, Tombstone, Arizona, and its several subwatersheds, ranging from 0.9 to 58 square miles, shows that

their rise times are inversely related to the watershed size. This is probably due to combined effects of high transmission losses and translatory wave movement in the channel system. The rise-time (not the same as "time-to-peak") appears to be a usable basis for developing characteristic sets of dimensionless hydrographs of such watersheds. Dimensionless hydrographs so developed fall into general classes--depending on the antecedent moisture level of the channel alluviums. (SWC 2-g2)

G. Watershed Models

1. Physical characteristics of watersheds. A program was initiated by the Hydrograph Laboratory, Beltsville, Maryland, to assemble existing documents on physical characteristics of ARS experimental watersheds for use in developing techniques for predicting infiltration and for routing runoff. Preliminary interpretations and analyses indicate that soil depths and land slopes are directly related to the amount of rainfall retained and the sequential routing of runoff. (SWC 2-aD1)

2. Digital models. A digital model for predicting streamflow being tested at Beltsville, Maryland, is composed of mathematical techniques and computer subroutines developed in the Hydrograph Laboratory. Rainfall is entered into the computer as tabulated from field observations. Infiltration capacity is computed as an exhaustion function and deducted from rainfall to derive rainfall excess. Source-area hydrographs are generated by sequential routing of rainfall excess through half of the watershed storage indicated by the recession storage constant for a particular watershed. Source-area hydrographs are routed through channel storage by the simultaneous solution of the equations of motion and continuity of mass, or by an approximation method substituting cross-sectional rating functions for the equation of motion. The computer model has been developed on modest equipment. Consequently, punch-out and re-entry are required to provide selection of the desired technique for channel routing. However, the program is written in FORTRAN II and is readily adaptable to larger and faster machines for extensive testing. (SWC 2-aD1)

Effects of transmission losses from the point of runoff generation to the outlet of a watershed, and translatory wave movement in the channel systems, typical of Southwestern ephemeral streams, render inadequate many common hydrologic concepts as bases for estimating flood flows, according to findings of the Southwest Watershed Research Center, Tucson, Arizona. The fact that flow losses begin immediately as runoff moves from its point of origin invalidates the notion that a simple relationship of rainfall to rain-site infiltration controls surface runoff at any point downstream; and nonlinearity in the true rainfall-runoff relationship at any significant distance from the source also makes the unit hydrograph a doubtful tool for synthesizing the hydrographs of arid and semiarid watersheds. These unique characteristics of watersheds in the Southwest, combined with rainfall inputs that are highly varied in both space and time, require a much more complex and sensitive mathematical model for runoff prediction than any so far developed. (SWC 2-g2)

The problem of synthesizing outflow hydrographs from large semi-arid watersheds, when the inputs are scattered, small-area, high-intensity thunderstorms of short duration, and transit functions include large transmission losses and translatory waves, is so involved as to defy solution by conventional mathematical techniques. Two approaches have been initiated in the past year to develop and test automatic computer models: (1) Electronic analog modeling of rainfall input patterns and certain of the most complex basin functions of the Walnut Gulch Experimental Watershed, in cooperation with the Utah State University Water Research Laboratory; and (2) Digital computer watershed model concepts being developed by the staff of the Southwest Watershed Research Center at Tucson. Both approaches will be pursued simultaneously, and meaningful solutions from the analog modeling may be used to modify the digital model, or vice versa. The anticipated end result is a hybrid model incorporating certain features of both analog and digital computer simulation techniques. (SWC 2-g2)

H. Hydrologic Data Releases

The compilation and publication of selected hydrologic data for all Agricultural Research Service experimental watersheds is a continuing program. USDA Misc. Pub. No. 994, "Hydrologic Data for Experimental Agricultural Watersheds in the United States 1960-1961", was published by the Government Printing Office in May 1965. Work on hydrologic data sheets for 1962, 1963, 1964, and 1965 is progressing. The hydrologic data consist of: Monthly precipitation and runoff; annual maximum discharges and annual maximum runoff volumes for various durations from 1 hour to 8 days; daily precipitation, air temperature, and discharge for the larger experimental watersheds; tabular data and graphs for selected runoff events; description of various watershed characteristics; and topographical, geological, and isohyetal maps. (SWC 2)

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AREA 3: HYDRAULICS OF IRRIGATION, DRAINAGE, AND WATERSHED STRUCTURES, CHANNELS AND FACILITIES

Problem: Water control structures of various types represent the largest part of the public and private cost for watershed protection and development programs. They are also essential, and expensive, features for irrigation and drainage developments. Research on the hydraulic design of water control structures will reduce the possibilities of overdesign, which increases the costs unjustifiably, or underdesign, which may result in costly failure. All items of costs not required for safe functioning of structures must be eliminated.

Development of new concepts in the geometry of spillways, drop structures, and stilling basins at pipe outlets and below overfall structures are included in this research. Other studies include development of new and improved devices for control of floating debris and vortices at the entrance to closed conduit spillways; investigations of energy losses associated with various components of water control structures, hydraulic jumps, the dynamics of overland flow and flood wave velocities and energy gradients in channels of various roughnesses; and development of improved flumes, weirs, gates, and rating sections for streamflow and water discharge measurement. The hydraulic properties of various grasses and other vegetation in water channels are also determined and the effectiveness of mats and mulching materials as an aid in the establishment of grass-lined channels and waterways are tested and evaluated.

It is not possible nor desirable to model the many hundreds of agriculture-related water control structures built each year, as is the usual custom with the larger dams and spillways on the main river systems. This research, instead, seeks to establish principles and develop dimensionless designs which can be adapted to various site situations and size requirements on individual farms and ranches and in upstream watersheds.

USDA AND COOPERATIVE PROGRAM

The Division has a continuing long-term program in which hydraulic and agricultural engineers are engaged in both basic and applied research on the hydraulic performance and engineering design of water control structures and channels. The studies are oriented primarily to provide information relating to the types of structures and channels involved in group irrigation, drainage and watershed protection activities.

The scientific effort devoted to this area of research totals 5.7 man-years in the reporting period. Of this number 1.5 are devoted to basic studies of hydraulic phenomena; 3.2 to criteria for hydraulic design of water control structures; and 1.0 to flow measurements and water metering devices.

PROGRAM OF STATE EXPERIMENT STATIONS

A total of 5 scientific man-years is devoted to this area of research.

PROGRESS -- USDA AND COOPERATIVE PROGRAMS

A. Basic Studies of Hydraulic Phenomena

Basic hydrodynamic equations of open channel flow were reconstituted in the Hydrograph Laboratory, Beltsville, Maryland, for simultaneous solution of equations of motion and continuity of mass. Using basic channel geometry and hydraulic parameters as input, the solution predicts stream regimen by continuous accountings of energy dissipation and disposition of inflow volumes to storage or outflow. The tedious and costly computations of water surface profiles are eliminated with this technique. Another advantage is the feasibility of computing both depth and duration of flooding during the routing process. The simultaneous solution is well suited to flood calculations in nonprismatic channels because backwater due to channel constrictions or to tributary inflows are automatically accounted for by dispositions due to changes in velocity and depth of flow. (SWC 2-aD1)

An approximation technique was also developed in the Hydrograph Laboratory, Beltsville, Maryland, for flood routing by the full continuity equation with a single-valued rating function substituted for the equation of motion. The basic formulation for storage routing is:

$$\frac{\partial Q}{\partial x} + \frac{A}{t} = \pm q \qquad \text{(Continuity)}$$

and

$$Q = f(A)$$

where Q is flow rate, cfs; A is flow area, $ft.^2$; q is lateral inflow (+) or lateral outflow (-); x is distance coordinate, ft.; and t is time coordinate, sec. Solution is by iteration, using an IBM 1620 (40K) computer. The computer program is operational for a wide selection of problems: (1) hydrograph inflow on a dry channel or base flow; (2) overland flow; (3) upstream inflow. Calculations appear to be only slightly influenced by reach length, but they are strongly influenced by the time increment selected. Best results were obtained by selecting a time increment equal to a fraction of the time to peak (t_p) of the inflow hydrograph. (SWC 2-aD1)

The classical flow equations of Chezy and Manning were reformulated in the USDA Hydrograph Laboratory, Beltsville, Maryland, to permit the direct computation of retardance coefficients from measured velocities and measured channel geometries. When velocity is plotted against a joint function of the flow area, the wetted perimeter, and the channel gradient, the cotangent or reciprocal of the slope is the retardance factor for that channel. A break occurred in the slope, indicating greatly reduced velocities below an associated depth of flow which varied with channel roughness. Breaking the slope of the relationship at this depth significantly improved the predictability of flow velocities. It also opened a whole new area of research envisioning two distinct types of flow: a sieve type of flow as interflow below, and a shear type of flow, or overflow, above some depth associated with the substance and stature of the material constituting channel roughness. (SWC 2-aD1)

At Stillwater, Oklahoma, studies of spatially varied flow in a grass-lined channel showed that available theoretical expressions for this flow can yield a good prediction of the water surface profile if the proper momentum coefficient and resistance relationships are used. (SWC 3-e1)

A series of six flood wave recorders were installed on the Alamogordo Creek Watershed, Santa Rosa, New Mexico, in the past year. Based on flood wave velocities measured so far on the Walnut Gulch Experimental Watershed, Tombstone, Arizona, it appears that flood wave depth-velocity relation is generally about midway between that of normal channel flow (with a Manning's n-value of 0.035) and that of pure gravity waves, $v = \sqrt{gd}$, with the latter as the upper limit. (SWC 3-g1)

B. Criteria for Hydraulic Design of Water Control Structures

At Stillwater, Oklahoma, tests of a full-size drop inlet entrance to a 24-inch-diameter concrete pipe spillway showed that an orifice plate placed on the crest of the drop inlet to reduce the flow must be vented if the orifice is to control the flow. Without an air vent, a vacuum develops within the drop inlet which adds to the effective head on the orifice. A simple diagram was developed which shows head, water discharge, and the air flow that is required at various heads and water discharges to maintain a particular head-discharge combination. (SWC 3-e2)

At Stillwater, Oklahoma, a new two-way, 1 x 3-foot, concrete drop inlet for a 24-inch concrete pipeline has been built to serve as a base structure for trash rack tests. An open-top rack, similar to one of the Soil Conservation Service standard designs, was mounted on this base and tested. Coefficients of discharge for clear water flow in this large test structure agreed with those obtained from tests on a small model. (SWC 3-e2)

C. Flow Measurement and Water-Metering Devices

At Stillwater, Oklahoma, model studies determined the best location, orientation, and elevation for a Tombstone flume at Site 7 in Walnut Gulch, Tombstone, Arizona. Subsequent model tests provided the calibration for the flume. (SWC 3-e1)

Also at Stillwater, Oklahoma, model studies developed and calibrated a combination pipe arch culvert-V-notch weir water meter. The V-notch weir provides sensitivity of measurement in the low-flow range and the culvert provides the control and satisfactory sensitivity of the measurement in the high-flow range. (SWC 3-e1)

Manning's n-values were calculated for Walnut Gulch, Tombstone, Arizona, from data obtained on July 22, 1964, by personnel of the Southwest Watershed Research Center. Walnut Gulch is a dry, ephemeral, steep, sandbed stream with some brush along its banks. The n-value for a uniform reach ranged from about .03 for a hydraulic radius of 1.5 to about .04 for a hydraulic radius of 6.5. The field values agreed well with the Manning's n-values of the model employed in rating the measuring flume at the downstream end of the reach in which the n-values were obtained. Since the measuring flumes are sensitive to approach velocity, it is essential that the roughness of the channel in the model be equivalent to the roughness of the channel in the field. (SWC 3-e1)

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AREA 4: CONSERVATION OF WATER SUPPLIES FOR AGRICULTURAL USE

Problem: The increased competition agriculture is facing from industry and domestic users for a limited water supply requires the development of new sources of farm water supply as well as increased efficiency in the collection, storage, conveyance, and use of existing supplies.

An estimated 12 million acre-feet of water is lost annually by evaporation from large reservoirs and 20 million acre-feet during conveyance in irrigation water canals.

Falling water tables resulting from withdrawals exceeding recharge are increasing pumping costs and the danger of depleting the supply over an appreciable area.

The conversion of cropland to grazing land requires an adequate livestock water supply strategically located to preserve the newly developed pastures. This is also a critical problem on many established dryland grazing areas.

The rapidly increasing use of farm chemicals poses a potential threat to the quality of water moving off of or through the soil of farm fields. Knowledge of the mechanics involved and the magnitude of the threat is needed so the development of management methods to prevent contamination of urgently needed water supplies can move forward without delay.

Phreatophytes are charged with using 20 to 25 million acre-feet of water in the 17 Western States. Eradication on nonbeneficial plants and replacement with vegetation of economic value would greatly benefit rangeland areas.

USDA AND COOPERATIVE PROGRAM

The Division conducts both basic and applied research and development in the area of water conservation, employing agricultural and hydraulic engineers, soil physicists and chemists, and geologists. The work is in progress at the U.S. Water Conservation Laboratory, Phoenix, Arizona, and at physiographic area research centers and field stations throughout the United States. In addition, four PL-480 projects on water conservation are in progress in Israel. The scientific and engineering effort in this area totals 21.6 professional man-years per year. Of this total, 6.3 are devoted to control of seepage from water structures and suppression of evaporation from surfaces; 4.4 to farm water supplies, structures, and water measurement; 5.9 to methods, practices and devices for ground water recharge; and 5.0 to contaminated and wasted waters.

PROGRAM OF STATE EXPERIMENT STATIONS

A total of 5 scientific man-years is devoted to this area of research.

PROGRESS -- USDA AND COOPERATIVE PROGRAMS

A. Control of Seepage from Water Structures and Suppression of Evaporation from Surfaces

1. Seepage. The loss of water from water collection, conveyance or storage structures is a real loss to the immediate farmer even though seepage water that moves to the ground water may be later recovered by pumping. When seepage causes high water tables, drainage and salinity problems frequently result.

At the U. S. Water Conservation Laboratory, Phoenix, Arizona, laboratory studies of soil deflocculation by various sodium salts showed that the anions significantly influenced the magnitude of deflocculation. Generally, the sodium phosphate and sodium carbonate salts were much more effective in dispersing soils than were sodium sulphate and sodium chloride. This work bears directly on the use of dispersants for reducing seepage from stock ponds. When water entering the pond contains calcium, which causes flocculation and increased soil permeability, sodium carbonate can be added to the pond water to precipitate the calcium as calcium carbonate. How much sodium carbonate to add can be determined by the use of the calcium carbonate saturation index. Once the amount to be used is established for a given condition, a simple pH measurement of the treated water can be used to check the efficiency of the treatment. (SWC 4-gG3)

A rapid and simple method for calculating the hydraulic conductivity of soil in the field has been developed at the U.S. Water Conservation Laboratory. The device consists basically of a 10-inch infiltration cylinder with lid, a standpipe with reservoir, and a vacuum gage with memory pointer. With this piece of equipment, the pressure at which air enters saturated soil is measured. Based on the assumption that this value is a reasonable estimate of the pressure head at the advancing wet front, the hydraulic conductivity of the wetted zone can be calculated. Multiplying this value by 2 yields the hydraulic conductivity for saturated conditions. A laboratory evaluation showed good agreement between hydraulic conductivity measured with the instrument and the known conductivity of several soils. With such a simple field device, the hydraulic conductivity and air entry values can be determined very rapidly. Usually, not more than 20 minutes are required per test. Information on the hydraulic properties of soil is necessary when designing irrigation systems, searching for recharge sites, and other similar projects.

Small, rapid-response piezometers were designed for use with the double-tube permeameter when measuring the horizontal and vertical hydraulic conductivity of soils. Laboratory tests showed that small-diameter piezometers with shielded (recessed), screen-covered openings should be used to obtain fast response, with minimum soil and pressure

disturbance. However, these piezometers should be inserted in the soil as slowly as practical. (SWC 4-gG1)

In field trials of the new method developed at the U.S. Water Conservation Laboratory for repairing cracks in concrete-lined channels, 800 feet of cracks were covered with 10 gallons of the sprayable sealer in 1 hour.

This involved three men--one cleaning with the water jet, one spraying the sealer, and one driving the equipment truck. The cracked area is cleaned with the high-pressure water jet (400 p.s.i.) and the crack sealer is sprayed (1500 p.s.i.) on the wet concrete. Commercially available equipment is used for both operations. Laboratory and field investigations show that the cleaning and spraying methods, as developed, have several advantages over other repair methods. Cracks in a silt- and algae-encrusted concrete lining can be rapidly and effectively located and cleaned with the high-pressure water jet. Materials to seal cracks by covering and/or filling can be rapidly applied and tightly bonded to wet concrete with the high-pressure spray equipment. (SWC 4-gG1)

Bentonite seals in experimental reservoirs in western Nevada are still highly effective three years after installation. These seals, buried under 6 inches of soil, are of two types: (1) a pure membrane of bentonite, and (2) a blanket of bentonite-soil mix. Seepage of untreated control reservoirs averaged 1.99 ft./day as compared with 0.114 ft./day for the blanket and 0.033 for the membrane treatment during 1965. (SWC 4-g3)

Installation of test sections of steel canal liners at Logan, Utah, revealed that an accurately shaped invert is essential to satisfactory alignment of trapezoidal liners. This requires specialized ditching equipment. However, a semicircular liner can be installed with equipment available to most farmers and lends itself to do-it-yourself farmer installation. Manufacturing costs of the semicircular liner are expected to be less than for the trapezoidal liner. (SWC 4-g3)

Butyl-coated fiberglass has shown exceptional resistance to deterioration in exposure tests at Logan, Utah. After exposure on a roof as a walking deck for 15 years, it retained a tensile strength of 1200 p.s.i. and 240 percent elongation. After 10 years of service as an exposed canal lining, this material had a tensile strength of 1870 p.s.i. and 300 percent elongation--essentially the same as original material. Of the plastic and elastomeric materials tested, butyl continues to be the most resistant to weathering and the only one satisfactory for exposed linings. However, buried vinyl and polyethylene film linings continue to provide essentially complete seepage control after 12 years in test reservoirs. (SWC 4-g3)

2. Evaporation from soil and plant surfaces. The resistance a plant offers to the evaporation process was studied at the U.S. Water Conservation Laboratory in 1965 with sorghum as the experimental test crop. This study, which was made to determine the relation between directly measured values

of leaf resistance to evaporation and calculated values of the entire canopy resistance, consisted of allowing the soil reservoir to become largely depleted and then irrigating the field to restore maximum availability. Although the precision of measurement is open to improvement, the data show a numerical agreement between the leaf and canopy resistance and suggest that the canopy resistance is about one-half the leaf resistance for a sorghum crop that is on the verge of pushing out its influorescences and has a leaf area index of 3.5. The study as a whole has clarified the physics of an evaporating crop short of soil water: dehydration of leaf tissue produces a partial stomatal closure and the resultant increase in diffusion resistance changes the partition of radiant energy input. Besides the reduced evaporation rate, the role of the canopy regulation is also evident in that leaf temperature during the day will exceed ambient temperature rather than be lower as is the rule with well-watered sorghum. (SWC 4-gG2)

During 1965 a "survival still" for obtaining emergency drinking water from soil and plant materials was developed at the U.S. Water Conservation Laboratory. Calculations were made using diffusion theory for water flow through soil to determine the possible water yield from soil using solar distillation. Mathematically predicted yields from these survival stills were very close to those found experimentally. These calculations show that theoretical soil water movement relationships can be used quite successfully to predict evaporation from soil surfaces. (SWC 4-gG4)

Experiments were conducted at the U.S. Water Conservation Laboratory to determine the proper location of meteorological instruments in an irrigated field to avoid influence by border or edge effects. The results imply that a fetch in meters 20 times the windspeed in meters per second is required for valid calculations of evapotranspiration by the Bowen ratio method when the highest measurement is 40 cm. above the crop or soil surface. (SWC 4-gG2)

In six seasons of operation, eight of eleven ET tanks installed at Winnemucca, Nevada, have developed leaks chiefly because saltgrass rhizomes punctured the 20-mil black polyvinyl plastic film lining. In field tests of resistance of various sheet materials to saltgrass puncture, all butyl samples 3/32-inch or thinner, and all plastic sheeting material (22 mil was the heaviest tested), were punctured by saltgrass rhizomes. Butyl sheeting should be at least 1/8-inch-thick in order to resist puncture when used as a buried membrane or otherwise held in firm contact with soil containing actively growing saltgrass rhizomes. (SWC 4-g1)

3. Evaporation from water surfaces. Studies were conducted at the U.S. Water Conservation Laboratory with floating white granular materials and with other materials and designs for floating covers to reduce evaporation from water surfaces. A six-month study with the granular materials showed the chopped styrofoam, which initially reduced evaporation 60 percent,

gradually decreased in effectiveness to 12 percent. Foam plastic beads, which initially reduced evaporation 42 percent, decreased in effectiveness to 29 percent. Present indications are that evaporation can be reduced 25 to 50 percent for periods of six months or more with floating granular materials if wind movement of the materials can be controlled. A floating cover of 30-mil black butyl covering 93 percent of the tank area reduced evaporation by 90 percent. After painting the same cover white, evaporation was reduced 96 percent. (SWC 4-gG2)

Three years of records from two evaporation pans at Winnemucca, Nevada, show that evaporation from a standard Weather Bureau-type pan refilled weekly and not cleaned during the growing season will give results within ±1.5 percent of a daily serviced, clean pan on a seasonal total basis. Unless daily readings are desired, there appears to be no advantage in daily servicing of pans as compared with weekly servicing. Seasonal evaporation from a daily serviced, clean pan during the three growing seasons ranged from 48.21 to 51.09 inches at Winnemucca. (SWC 4-g1)

B. Farm Water Supplies, Structures and Water Measurement

1. Water harvest. Supplemental irrigation has been shown to be extremely important in increasing yields in many locations in subhumid and humid regions, especially during periods of drought. The availability of water for irrigation is the key to successful supplemental irrigation in these regions. In Missouri, a probability analysis of the precipitation and runoff records that relate to a 90-acre-foot capacity reservoir having a drainage area of 154 acres has been made. In 1965, a year of approximately normal precipitation, it was shown that 118 acres of land could have been supplied with 8 inches of supplemental irrigation water even though runoff was slightly below the long-time average. Based on a 25-year record and with reasonable assumptions regarding other factors affecting the water balance, the probability of potential amounts of water available for irrigation from this watershed has been determined. Considering 8 inches to be the usual amount of water needed for supplemental irrigation, this watershed and reservoir will supply about 114 acres of land with this amount of water 50% of the time; 60 acres, 80% of the time; 41 acres, 90% of the time; and 30 acres, 94% of the time. This information will serve as a basis for design of supplemental irrigation systems in this and similar areas. (SWC 4-c1)

Preliminary observations on dug pits for irrigation water collection and storage in the Atlantic Coast Flatwoods land-resource area, Tifton, Georgia, show that site location has a major effect on the water yield of the pit. One pit beneath a sloping field of Tifton sandy loam overflowed during 9 months of 1965. A second pit in nearly level topography of Klej loamy sand never overflowed, and was filled to maximum capacity only during January through April. (SWC 4-b1)

Discoloration of rainfall runoff from sprayed asphalt pavements used for water harvest catchment areas at the U.S. Water Conservation Laboratory was reduced by applying a flaked aluminum spray-coating to protect the asphalt against solar radiation. The discoloration is caused by photo-oxidation of the asphalt. A spectrophotometric analysis of the water showed that the degree of discoloration was a function of dilution only, permitting colormetric evaluation of the quantity of coloring material in the water. Coloration was expected to be inversely proportional to the quantity of runoff water and directly proportional to the time interval between rains. A plot of color index versus days between rains divided by runoff in millimeters was surprisingly linear. The data showed that the aluminum spray reduced water discoloration by 40% as compared with an asphalt-clay emulsion coating.

Runoff from a 2,500 sq. ft. smoothed soil plot treated with a water repellant averaged 94% of the measured rainfall. Runoff from a smoothed plot without a water repellant was 33%, and runoff from two untreated watersheds was 22%. Contrary to expectations, erosion from the water-repellant sandy loam soil was not significantly greater than from untreated soil. Cost of applying the water repellant was $250 per acre. These findings constitute a significant breakthrough towards truly low-cost water harvesting. Conservative calculations indicate that in 20-inch annual rainfall zones, treatments of this type can produce water for less than 20 cents per thousand gallons. (SWC 4-gG3)

A PL-480-supported study at the Volcani Institute of Agricultural Research, Rehovot, Israel, showed that both the surface crust and the underlying layers affect the infiltration capacity of a soil. Mathematical treatment and experimental results indicate the possibility of predicting infiltration capacities on the basis of measurable properties of both the crust and the subcrust layers. When artificial crusts are to be formed for runoff inducement, this development will aid in determining desirable crust properties. Preliminary analyses of field data indicate sodic crusts are very effective in sealing but are not sufficiently stable to withstand erosion. Various petroleum derivatives, mainly based on several grades of fuel oil, appear to have desirable stability and sealing characteristics but present problems of bonding to the soil surface, particularly for those soils subject to swelling and shrinkage with moisture changes. (A10-SWC-36)

2. Water measurement and control structures. An integrating velocity profile meter to measure the flow of water in irrigation channels has been developed at the U.S. Water Conservation Laboratory. It measures the force exerted on a rectangular blade by a flowing stream. The blade is long enough to extend from the water surface to the channel floor and is placed broadside to the flow. The total force exerted by the stream-flow is measured as a torque about a vertical edge of the blade. A comparison of the average stream velocity value obtained by using the meter with that obtained by pitot tube techniques showed a standard

deviation of 1.5%, based on 16 tests. The device seems promising for rapid measurements of average velocity in shallow water flows as well as in channels.

Continued studies of chemical tracers for measuring water flow showed that Rhodamine WT is not significantly adsorbed on channel boundaries. Laboratory studies showed a low adsorption rate as compared with Rhodamine B and Pontacyl Pink B. Flow measurements were made in a 48-inch-diameter pipe with the dye dilution method using Rhodamine WT and with a calibrated Cole Pitometer. Measurements were identical for one day's run and differed by only 0.4% for a second day's results. Adsorption of Rhodamine WT on suspended sediments and channel boundaries appears to be undetectable in ordinary applications. (SWC 4-gG5)

The nylon-reinforced butyl rubber valve used to remotely control irrigation water discharge through farm ditch turnouts has been further adapted to regulate rate of flow by controlling the degree of inflation. Application of this development to maintain a constant rate of discharge at the farm headgate or from overnight storage reservoirs regardless of variations in headwater or tailwater levels offers further possibilities for semi-automated water deliveries by irrigation districts or by operators of large irrigated farms where storage reservoirs are used. Results of laboratory studies at Fort Collins, Colorado, have shown that the lay-flat inflatable valve, in conjunction with a measuring flume, can maintain discharge within 5 percent during wide fluctuations in canal or reservoir levels. Limitations include: (1) the flume discharge must not be submerged, and (2) the control switch must be adjusted manually to change discharge rate, if required. The latter limitation would not apply to a single preselected discharge rate. (SWC 4-3(d1) Rev.)

C. Methods, Practices and Devices for Ground Water Recharge

1. Recharge methods and facilities. Further analyses of data and observations obtained from 2-acre, pilot-study recharge basins near Fresno, California, have shown that the displacement of air in soil pores, as the wet front descends beneath a recharge basin, influences the apparent and real hydrograph of mound development on the water table. Because of localized response at each observation well to air pressure beneath the advancing wet front, an apparent rise in water table is indicated prior to actual recharge. This measurement difficulty can be overcome by detecting the position of the wet front with neutron probe moisture measurement techniques. It was also shown that the descending wet front curves significantly, and continued storage changes above the water table cause the recharge rate to be a time-dependent function. However, if proper corrections are made for the influence of air movement, available theoretical analyses can be used to adequately describe the buildup of a ground-water mound beneath a square recharge basin.

A shallow perching layer of large areal extent was delineated in western Fresno County, California. The water table associated with this layer is presently rising at the rate of approximately 1 foot per year. Indications are that this water table developed and has continued to rise because of irrigation started in the 1940's, and that it will have a major influence on farming operations from a drainage standpoint as well as on limiting recharge to the deep aquifer zone presently pumped for irrigation supply. (SWC 4-g2)

At Bushland, Texas, field tests showed that 6-inch "domestic-type" water wells could be successfully used as ground water recharge wells. Six-inch wells are relatively inexpensive to construct. About 45 acre-feet of water was recharged through two 6-inch wells. The suspended sediment content of the recharge water varied from 10 to 30 p.p.m. The flow rate into the wells gradually decreased owing to formation clogging by the suspended sediment. The wells were redeveloped by bailing, which is an inexpensive, simple process. Large quantities of sand moved into the wells during bailing, but had no adverse effect on the wells. (SWC 4-13(e2))

2. Water clarification. At Bushland, Texas, a simple field system removed more than 90 percent of the suspended solids from 94 acre-feet of muddy runoff water, and 61 acre-feet of the treated water was recharged into the Ogallala formation through wells. The recharge system included in order: Cationic coagulant injected on suction side of centrifugal pump, discharge passed through flow rate measuring flume, aluminum sulfate injected at flume outlet, slow mixing in farm irrigation ditch, sedimentation in excavated basin, and recharge into wells by gravity flow. The system tested was much simpler and less expensive than city water treatment plants, yet it removed sediment almost as effectively. Field system performance followed closely the results of laboratory jar tests. Further research is needed to develop a compact system that can be used on farms and ranches. (SWC 4-13(e2))

In a PL-480-supported study at Technion-Israel Institute of Technology, Haifa, Israel, playa lake sediments from Bushland, Texas, were used to provide synthetic playa runoff water for flocculation testing. These tests showed that anionic polymers were not effective as a flocculant. There were deviations in flocculation behavior in comparison with suspensions of reference clay minerals. Higher doses of alum and cationic polymers were required. Complete clarification of the playa water with polyelectrolytes was difficult. This was attributed to organic and inorganic impurities. When organic matter was leached from the sediment, polyelectrolytes were as effective as when used on the reference clay minerals solutions. Final turbidity of 5-10 mg./l. was obtained by a combination of 30-40 mg./l. of alum plus 3 to 4 mg./l. of Purifloc C-31 (cationic). (A10-SWC-25)

D. Contaminated and Wasted Waters

1. Chemical water contamination--mechanics and control. The widespread use of pesticides and other agricultural chemicals has led to charges that these materials, essential to efficient agricultural production, are polluting surface and ground water supplies.

Studies at Watkinsville, Georgia, showed that the loss of 2,4-D in washoff (runoff + soil loss) was reduced by increasing the time between the chemical application and the rainfall, by lower temperature of rainwater, and by using the amine form instead of the ester form of the chemical. Losses of the amine form of 2,4-D were lower because it is more soluble than the ester form and thus was carried several inches deeper into the soil by the infiltrating rainwater. The ester form remained on or in the soil surface, where it was more readily available for movement in the surface runoff and eroded soil. (SWC 4-14(b2))

Data from studies initiated in 1965 at Watkinsville, Georgia, indicate that losses are quite low from Atrazine applied to bare land, as in a preemergence treatment for corn. Under very severe conditions where a rainstorm of 2½ inches in 1 hour was applied 1 hour after the broadcast application of 3 lb./acre of the chemical, the loss rate was only 0.50 lb./acre, or 1.4 p.p.m. in the water and soil lost from the land. When the chemical was applied 96 hours before the rainstorm, the loss was only 0.22 lb./acre, or 0.6 p.p.m. Both these cases are from extreme conditions where the entire runoff area was treated and the surface conditions as well as the intensity and timing of the rain favored high losses. Normally, only a part of a field or watershed is treated with a chemical at one time, and rains are not as severe as the test storm used in these studies. All of the Atrazine remaining in the soil was recovered in the surface 6 inches, with most of it in 3 inches, indicating there is little downward movement of this chemical in the soil profile. (SWC 4-14(b2))

The high rates of nitrogen fertilization used on many farms have raised a question concerning the effect this may have on water quality. Preliminary investigations at Watkinsville, Georgia, indicated that nitrogen losses are extremely low in runoff water from Cecil soil of moderate land slope. A rainstorm of 5.0 inches was applied at 2½ inches per hour in four consecutive periods separated by 10-minute intervals immediately after 200 lb./acre N from ammonium nitrate was broadcast. The storm washed off only 2.3 and 0.3 percent of the fertilizer from fallow soil and a grass sod, respectively. Losses of nitrogen from the fallow plots were about equal for the first 3 rainfall increments and showed evidence of tapering off during the fourth increment. Runoff averaged 80 percent of total applied rainfall. On the sod plots, the loss of nitrogen was almost entirely confined to the fourth storm increment. Runoff averaged 12 percent of total applied water, with 86 percent of this runoff occurring during the fourth storm increment. The probability of a 5-inch storm of this intensity in a 2½-hour period is approximately

once in 80 years. A storm of half this size would occur about once in five years. (SWC 8-b1)

At Dubois, Indiana, on Zanesville silt loam of 13 percent land slope the loss of nitrogen from a 5-inch rain at 2½ inches per hour was 2.2 and 2.3 percent from fallow and sod, respectively. Runoff from the sod in these tests occurred during all storm increments and totaled more than double that from the sod in the Georgia tests. But when a second and similar storm was applied 3 days later, 2.8 and 3.17 percent additional nitrogen was washed off the fallow and sod plots, respectively. When the ammonium nitrate was applied before the second 5-inch storm, washoff from the fallow and sod plots was 6 and 15 percent of the applied amount, respectively. (SWC 8-c2)

These preliminary data suggest that there may be little probability of water contamination from use of nitrogen fertilizer under normal conditions, but that with surface applications that are followed immediately by extreme storms that cause high runoff amounts, some contamination may occur.

Measurements of nitrate-nitrogen below the root zone in the sugar beet study at Twin Falls, Idaho, indicated that the concentration of this material decreased to a low level earlier in the season when excessive irrigations were used. These data, when combined with cumulative deep percolation losses, indicated about 35 lbs. of nitrate-nitrogen per acre were leached without excessive irrigations and about 90 lbs. were leached with excessive irrigations. (SWC 5-f1)

2. Reclamation of water wasted by phreatophytes. Results of a revegetation feasibility study in the Paradise Valley area of Nevada show that supplemental water must be applied to establish grasses after removal of phreatophytes (brush). The supplemental water may be required for two or more seasons before the grass root system is capable of drawing water from the capillary fringe above the water table. Root distribution with depth has not yet been determined. With respect to forage yields in the revegetation study, tall wheatgrass appears superior to both Great Basin wildrye and crested wheatgrass (desert strain). Plant growth in the study plots was closely correlated with microrelief and soil properties. Good growth occurred only on the soils of low dunes or hummocks which comprised about one-third of the plot area. Few plants became established on the playa soils between the dune soil areas. This confirms results predicted on the basis of high salinity, alkalinity, boron content, and poor physical condition observed in playa soil samples collected and analyzed before the study. (SWC 4-g1)

A 5-year study was conducted to explore the feasibility of providing the supplemental irrigation needed to establish grasses by pumping water from a shallow water table using a multiple-well system that could be installed by hand labor. Two multiple-well systems were developed:

a drive-point system and a small-diameter, cased-well system, each with necessary manifolding, pump, and power unit. The unit cost of the water was found to be contingent on the yield of the well system, the cost of the well installation, the type of pumping unit, and the hours of pumping per season. Based on current approximate costs, and certain assumptions regarding equipment selection, pumping rates, useful life, etc., the cost of producing an acre-foot of water ranged between 7 and 19 dollars. (SWC 4-g1)

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AREA 5: IRRIGATION PRINCIPLES, REQUIREMENTS, PRACTICES AND FACILITIES FOR EFFICIENT USE OF WATER ON FARMS

Problem: Competition now faced by irrigated agriculture from municipal and industrial users of water for the limited supplies available is forcing the adoption of improved methods of water application and use. Rigid adherence to historical methods of allocating water has not fostered efficiency. Often water is cheaper than the labor required to achieve more efficient use of water.

Irrigation, historically responsible for the existence of agriculture in the arid West, has become an economic necessity in the production of high-value crops in the humid areas where annual or seasonal droughts jeopardize both the quality and quantity of crops produced.

An estimated 30 million acre-feet of water are lost to the immediate farmer during irrigation application. This consists of losses to evaporation, deep percolation and tailwater runoff.

Improved solutions to many of the problems associated with the irrigation practice, such as use of limited water supplies, methods for efficient water application, optimum time and amount of application in relation to crop growth stage, soil factors, and a practical method of determining when to irrigate, would do much to increase water-use efficiency. Automation in water application has the potential for increasing water-use efficiency while reducing the cost of application. Temperature control by sprinkler irrigation to maintain high crop quality is an area needing further research attention.

USDA AND COOPERATIVE PROGRAM

The Division conducts both basic and applied research and development in irrigation, utilizing agricultural and hydraulic engineers, soil physicists, and soil scientists at various physiographic area research centers and field stations in the United States. Four PL-480 studies on irrigation are underway in Israel. The scientific and engineering effort in this area totals 23.4 professional man-years. Of this total, 12.8 are devoted to irrigation water requirements, crop response and soil-water relations; 6.6 to water application methods--surface, sprinkler and subsurface; and 4.0 to systems designed for efficient use of water and of labor.

PROGRAM OF STATE EXPERIMENT STATIONS

A total of 27 scientific man-years is devoted to this area of research.

PROGRESS -- USDA AND COOPERATIVE PROGRAMS

A. Irrigation Water Requirements, Crop Response and Soil-Water Relations

1. Water requirements. Seasonal evapotranspiration (planting to harvest) for sugar beets in southern Idaho on treatments producing maximum yields was 22 acre-inches in 1964 and 1965. The yields in both of these years were below average because of late planting dates and below-normal air temperatures. Seasonal evapotranspiration is expected to be 5 to 10 percent greater in years with earlier planting dates and normal climatic conditions.

Measurements of the reflectance of solar radiation from sugar beets at Twin Falls, Idaho, indicated only a very small increase from early August to late September as the mean elevation angle of the sun decreases and as the crop approaches the harvest date. Similarly, measurements made two hours before solar noon, at solar noon, and two hours after solar noon indicated insignificant changes in reflectance with turgid leaves before solar noon and leaves that tend to wilt in midafternoon. These studies showed that when a sugar beet crop is fully developed, the reflectance of solar radiation is nearly constant. The reflectance is used in estimating net radiation, which in turn is a major variable used in estimating evapotranspiration from irrigated crops and irrigation water requirements. (SWC 5-f1)

Two years of observations in a study to determine minimum water requirements of lawn grasses in cooperation with the U.S. Navy at Reno, Nevada, show that (1) on loam soil a 7-day irrigation interval is adequate for maintaining lawn grass in a top, well-dressed condition during the hot part of the growing season, (2) twice weekly irrigation is required on a sandy loam soil, and (3) pan evaporation, net radiation, or the Olivier method can be used to estimate lawn grass ET with comparative accuracy on a monthly or seasonal basis. (SWC 5-9(g2) Rev.)

Preseasonal irrigation is a common practice on about 2 million acres of pump-irrigated continuous grain sorghum in the Southern High Plains. In a preseasonal irrigation study at Bushland, Texas, a 5-inch application increased soil moisture after planting by only 0.2 inch over plots that did not receive the preseasonal irrigation. Varying the date of application from December 22 to May 24 on five dates did not influence soil moisture storage after planting. Preseasonal rainfall of 13.5 inches, which occurred mostly in late May and June after the last date of preseasonal water application, was adequate to wet the 6-foot profile to near field capacity on plots that did not receive the preseasonal application. Therefore, preseasonal irrigation decreased storage of rainfall following irrigation, did not increase grain yields, and decreased efficiency of water use in a year when preseasonal rainfall was much above average. (SWC 5-5(e1) Rev.)

The seasonal rate of soil water depletion by Coastal bermudagrass at Watkinsville, Georgia, was not affected by clipping frequencies of 2, 4, and 6 weeks nor by N-K fertilizer rates of 200-100, 600-300, and 1000-500 pounds per acre, but it was affected by available soil water. Average

seasonal soil-water depletion rates were 0.17 and 0.11 in./day with and without irrigation. Depletion was greatest in the top 9 inches of soil, and practically no water was extracted from the 21- to 27-inch layer. (SWC 5-b1)

The need for irrigation on cotton was predicted successfully at Thorsby, Alabama, by available climatic data and by plant appearance. Climatic data used were pan evaporation, net radiation, and average rates of water use previously determined. The deviations of the predicted daily rates of soil-water depletion from rates measured by soil sampling were ± 0.052 for pan evaporation, ± 0.048 for net radiation, and ± 0.062 inches per day for average rates from previous years. (SWC 5-b1)

Soil water records at State College, Mississippi, showed that the corn hybrid Mp 339 x Mp 311 extracted more water than did the hybrid Mp 305 x Mp 307 from the 5-foot-deep root zone during the entire fruiting season. These records demonstrate why there is less response in grain yield to irrigation during dry seasons with the former than with the latter hybrid, and show that genetic differences are important in efficiency of moisture use by crops. (SWC 5-b1)

Annual evapotranspiration (ET) from Tifway bermudagrass sod at Ft. Lauderdale, Florida, with the water table 24 inches beneath the soil surface, was 15.6, 26.1, 33.6, and 41.7 inches for zero, one-third, two-thirds, and full-sod cover, respectively. This relationship is expressed by the regression equation $Y = 44 + 0.56X$, where Y is the percent of potential ET and X is the percent of sod cover. Forage yields were 2 tons per acre from the full-cover plots, and 80 and 70 percent of this amount from the 2/3- and 1/3-sod cover, respectively. These data suggest that forage yield and water use can be predicted from sod density on land with adequate, but not excessive, drainage. (SWC 6-b1)

2. Crop response to water, fertilizer and other management practices for efficient water use. The effect of ten irrigation regimes and four harvest dates on the yield and sugar content of sugar beets was investigated at Phoenix, Arizona. Differences in yields between irrigation regimes ranged from 10 to 18 percent. The yields per harvest increased as the season progressed at a rate of about 1 ton per week from the first harvest in June until the last harvest at the end of July. Because of the general lack of statistical significance between irrigation treatments, it can be inferred that the beet plant can utilize moisture under conditions of high soil moisture stress and not show a great reduction in yield. Sugar percentage tended to increase when the plants were subjected to a dry soil moisture regime throughout the growing season. Seasonal consumptive use during 1965 was about 40 inches for maximum production at the late-season harvest. (SWC 5-9(g2) Rev.)

In irrigating high silt soils in southern Idaho, the slow rate of lateral subbing from irrigation furrows or corrugates often results in

overirrigation to assure wetting the area between the furrows. Farmers generally irrigate 24 hours per set in this area, which is about twice as long as needed on shallow-rooted row crops with rows spaced 22 to 24 inches apart. Studies at Twin Falls, Idaho, showed that sugar beet yields decreased 2 tons per acre when water was kept on the plots twice as long as necessary at each irrigation. Greater reductions occurred on plots where nitrogen had not been applied in 1965. (SWC 5-f1)

Studies at Twin Falls, Idaho, in 1964 indicated that maximum soil temperatures could be reduced, and minimum and average temperatures increased, by the use of water-filled plastic mulches. The degree of temperature attenuation depended on the depth of water maintained between the plastic layers. Studies in 1965 indicated that controlling soil temperatures within a range more favorable to crop growth with a water-filled plastic mulch resulted in earlier development of sweet corn ears coupled with larger early yields when compared to the check treatments. Similar results were obtained with green beans. (SWC 5-f1)

Lodging of grain sorghum resulting from charcoal rot (Macenophomina phaseoli) is a frequent problem in the Southern High Plains when the crop is grown under limited soil moisture conditions. At Bushland, Texas, when the last irrigation was applied during grain development, lodging was eliminated; when applied at heading, lodging was slight to moderate; and when applied during vegetative development prior to boot stage, lodging was slight to moderate; and when applied during vegetative development prior to boot stage, lodging was severe. Lodging severity appeared to be closely related to the degree of moisture stress incurred during the period of grain development through maturation. Lodging severity was increased somewhat on drier treatments by closer row and plant spacings which slightly accelerated development of moisture stress. (SWC 5-5(e1) Rev.)

A study at Blacksburg, Virginia, of two tobacco varieties, three plant spacings, and two levels of water availability showed that there was no difference in total number of leaves or leaf areas for different soil-water regimes at midseason. At harvest, leaf areas were significantly higher at high soil moisture tensions (25-100 percent available water) than at low tensions (75-100 percent available water). Leaf Area Indexes at harvest ranged from a low of 2.63 with Kentucky 16 for the low soil water tension, and 40 x 40-inch spacing, to a high of 6.73 with Kentucky Mammoth for the high soil water tension, and 18 x 42-inch spacing. In general, the Mammoth variety produced poorer quality tobacco and reflected a much sharper drop in value on the close 20 x 20-inch spacing than did the conventional Kentucky 16 variety. As observed during the past two growing seasons, lower yields obtained at high soil water levels indicate that soil aeration may be a factor inhibiting leaf development. (SWC 5-a1)

Further evaluation of the effect of evaporation suppression on water-use efficiency was carried out at New Brunswick, New Jersey, using a black plastic strip mulch which covered two-thirds of the ground surface. Results

on two soil types, Collington sandy loam and Freehold loamy sand, indicated that yield responses to mulching were conditioned to a large extent by the water-holding characteristics of the soil. No tomato yield increases resulted from mulching on the Collington soil, but a 6-ton-per acre increase was obtained on the Freehold soil. Irrigated plots, however, gave significant tomato yield increases over the nonirrigated mulched or control plots on both soils. (SWC 5-a1)

Irrigation during short periods without rain at Watkinsville, Georgia, increased forage production and nitrogen-use efficiency (lb. forage per lb. N applied) on Coastal bermudagrass. Forage yields were 2.78, 5.36, and 5.61 tons per acre without irrigation, and 3.90, 7.51, and 7.81 tons per acre with irrigation at N levels of 200, 600, and 1,000 pounds per acre, respectively. Nitrogen-use efficiency was 27.8, 17.9, and 11.2, without irrigation, and 39.0, 25.0, and 15.6 pounds per pound N with irrigation, respectively, for the same N applications. Crude protein of the forage was increased almost 2 percent by irrigation, but crude fat, ash, and crude fibre were not affected.

Irrigated cotton at Thorsby, Alabama, was outyielded by nonirrigated cotton in 1965 due to excessive damage by insects and diseases under the wetter conditions where rains followed soon after irrigations. This indicates the need for accurate rain forecasts when irrigation is planned in the humid area.

Corn at Watkinsville, Georgia, grown with 26,000 and 13,000 plants per acre, respectively, yielded 148 and 143 bushels per acre with irrigation and 111 and 116 bushels per acre without irrigation. (SWC 5-b1)

Forage corn was subjected to water stress during three different growth periods in a PL-480 supported study at the Volcani Institute of Agricultural Research, Rehovot, Israel. Stress during the period just preceding silking caused a marked reduction in height at harvest time, as well as a 15-percent reduction in dry matter. By contrast, water stress after silking showed no appreciable effect on dry matter at harvest time. Leaf permeability, determined with a field permeameter, furnished a measure of stomatal aperture which may serve as a satisfactory indicator of water status in the main root zone of corn. (A10-SWC-29.)

3. Water intake, transmission, storage and deep percolation. Low infiltration rates and limited water-holding capacities cause losses of rainfall and potential available water through surface runoff and percolation below the rootzone on many soils in the Southeast. Infiltration studies at Watkinsville, Georgia, with 8 cropping treatments on Cecil sandy loam soil showed the infiltration rate-time relationship during a high-intensity rainstorm could be described by the formula $Y = a + bX + cX^2$, where Y = infiltration rate, X is time, and a, b and c are constants. Application of appropriate constants in this formula showed that after 30 minutes of rainfall the infiltration rates in inches per hour were 1.06 from

corn grown continuously, 2.43 for corn after rye cover crop, 2.89 for corn after grass sod, and 3.91 for fescue and clover sod. Application of the appropriate formulae for 8 cropping treatments to all the rainstorms in the growing season for 3 years showed that, although there is more infiltration and less surface runoff on the areas with higher infiltration rates, there was very little difference in the amount of water stored in the soil profile. Most of the increased infiltration was lost through deep percolation because of inadequate storage capacity in the soil profile. This caused no difference in the calculated irrigation requirement for the 8 cropping treatments. (SWC 5-b1)

Results of studies at New Brunswick, New Jersey, stress both the importance of evaporation suppression for increasing water-use efficiency, and the significant contribution of upward movement of water from below the root zone. The control plots, which received 11.7 inches of rainfall, produced 30.4 tons per acre of tomatoes and showed an overall soil water depletion of 2.7 inches for the season. When the surface was covered with black plastic, 30.5 tons per acre of tomatoes were produced with only 5.2 inches of water stored in the soil, but with unrestricted vertical movement of soil water. When vertical movement was restricted by placing a plastic barrier at a depth of 3-1/2 feet, only 15.6 tons per acre were produced. The 5.4 inches of soil water depletion in the latter treatment, represented 90 percent of the total water stored in that soil volume. The black plastic surface cover increased soil temperatures and increased the yield of marketable tomatoes by decreasing soil rot. (SWC 5-a1)

Deep percolation, irrigation water losses, nonsteady-state drainage, and specific yield determinations involve solving one-dimensional unsaturated flow problems. Numerical solutions of several one-dimensional drainage problems were obtained using a digital computer in studies at Twin Falls, Idaho. The validity of these solutions, using hydraulic properties of the porous media obtained under steady-state conditions on independent samples, was demonstrated by comparison with experimental data. The outflow, fluid pressure distribution, and fluid distribution were very similar for identical problems. The studies showed that the rate of unsaturated drainage can be predicted with reasonable accuracy using a simple approximate solution published by Youngs in 1960 until the outflow is equal to about 0.6 of the potential outflow. A detailed analysis of the draining columns showed that the limit of Youngs' equation coincides with the time when the saturated front approaches the equilibrium position. Beyond this point Youngs' equation overestimates outflow rate.

Extensive areas of Portneuf silt loam soils are farmed in southern Idaho. These soils often have a cemented layer at a depth of about 18 inches that generally restricts root penetration. Field studies conducted at Twin Falls, Idaho, indicate that the hydraulic conductivity of the cemented zone is adequate so as not to restrict downward flow of water when the soil is near saturation. However, the hydraulic conductivity of this layer decreases very rapidly as the soil dries. The cemented layer

restricts the rooting depth of crops, but its hydraulic characteristics decrease the rate of drainage so as to increase the available-water-holding capacity. The available-water-holding capacity of the top 2 feet of this soil ranges from 2.3 to 2.8 inches per foot of soil depth. (SWC 5-f1)

The available-water-holding capacity of soils is related to the texture of the soil, but it also can be materially influenced by underlying coarse-textured materials. The prediction of the available-water-holding capacity of soils underlain with coarse-textured materials is essential in the development of new irrigation projects in the Pacific Northwest where these soils are common. Studies at Prosser, Washington, have shown that the amount of water retained by the soil, which decreases with time following an irrigation, can be calculated for any time using numerical procedures and a high-speed digital computer. The calculated results agree very well with measurements made in field plots. Utilization of numerical procedures also enables a rapid evaluation of the influence of the depth to the coarse layer, as well as the texture of the coarse layer, on the water-holding capacity. (SWC 5-f1)

The rapid determination of the water content of a finite surface layer of soil is often needed in research studies on the erodibility of soils, the estimation of reflectance in net radiation calculations, and for characterization of agricultural soils by remote sensing. Studies at Twin Falls, Idaho, indicated a smooth, decreasing exponential relationship between reflectance near 1.1 microns, and increasing water content on Portneuf silt loam for soil moisture tensions below 1/3 atmosphere. At soil moisture tensions greater than 1/3 atmosphere the effects of surface cracking, or macroscopic effects, altered the reflectance to the extent that a consistent relationship no longer existed. These studies illustrate the complexity of determining either surface water content or textural characteristics because reflectance in a given wave length range can be significantly influenced by macroscopic roughness effects in addition to both water content and texture of the surface materials. (SWC 5-f1)

B. Water Application Methods

1. Surface irrigation techniques, hydraulics and water infiltration. Wider-than-normal spacing of irrigation furrows offers possibilities for more efficient management of limited irrigation water on fine-textured soils in areas where rainfall furnishes a substantial part of plant water needs. Results from a study of 30-, 40-, 60-, and 80-inch irrigated furrow spacings on a 1900-foot length of run on Pullman silty clay loam soil at Bushland, Texas, indicate that spacing can be increased to 60 inches without adversely affecting intake, storage and distribution of irrigation water and efficiency of water use by grain sorghum. But increasing furrow spacing to 80 inches adversely affected distribution with length of run because of inadequate time for moisture absorption on the lower end. Sixty-inch furrows permit a somewhat smaller application and quicker irrigation of a field than do 30- and 40-inch furrows. (SWC 5-5(e1) Rev.)

Control or modification of the rate of water intake can result in more uniform application of irrigation water, or change the required irrigation duration to be more compatible with other farming operations. Studies at Twin Falls, Idaho, have shown that average seasonal furrow intake rates on Portneuf silt loam can be decreased about 25 percent by compacting the potato beds adjacent to the potato row. "Furrow slickers" commonly used to compact and smooth the furrows decreased average seasonal intake rate about 13 percent. Two furrows between potato rows essentially doubled the average seasonal intake on an area basis when compared to one furrow between rows. In contrast, irrigation in alternate furrows decreased the average seasonal intake rate on an area basis 42 percent when compared to every furrow irrigation. These data illustrate the magnitude of changes in intake that can be accomplished by the use of common tillage and irrigation practices. (SWC 5-f1)

A general solution to the infiltration-advance problem with particular solutions for specific intake functions was published recently. Computer solutions of the lengthy series for the case when the intake can be represented by an equation of the form $I = at^b$ have also been published recently. These solutions indicate a linear relationship between qt/cx and at^b/c where q is the unit flow rate, t is time, c is the average depth of flow and x is the advance distance. Analyses of the infiltration-advance relationships obtained in a Hele-Shaw viscous fluid model indicate that the model data also exhibit the same general linear relationship, but only for $at^b/c>2$. However, the Hele-Shaw data cannot be applied directly with a simple scaling factor because resistance function for the model is not the same as in the irrigation border strip. (SWC 5-f2)

A study at Logan, Utah, to determine factors influencing infiltration from irrigation furrows showed that water temperature variations along an irrigation furrow can result in 20 percent differences in viscosity. The increase in water temperature as it flows down a furrow may partially compensate for the contact time differences which result from the furrow stream advance. (SWC 5-8 (g1) Rev.)

The portable sprinkler irrigation evaluation device designed and constructed at Reno, Nevada, has proved useful for measuring the seasonal decline in intake rate commonly observed in furrows of row crops. Measurements in a potato field on silt loam soil showed that intake rates decreased from 0.44 inch per hour after the first irrigation to 0.24 inch per hour after the fourth irrigation, in furrows where tractor wheels passed. In furrows where tractor wheels had not passed, intake rates were 0.49 inch per hour and 0.38 inch per hour after the first and fourth irrigations, respectively. The sprinkler irrigation device will be useful in evaluating tillage and cropping systems as to seasonal and cumulative effects on intake rates in addition to its primary use as an irrigation system design tool. (SWC 5-8 (g1) Rev.)

Laboratory studies at Logan, Utah, show that irrigation syphon tubes with curved outlet ends will deliver a greater range of flows under free

discharge conditions than tubes with straight ends. Under field conditions, use of the curved outlet tubes will provide the farmer more flexibility in irrigation water control. (SWC 5-8(g1) Rev.)

2. Sprinkler irrigation techniques, equipment and water distribution. Previous studies at Twin Falls, Idaho, have shown that the amount of radiant and sensible heat available for latent heat evaporation controls evaporation losses during sprinkler irrigation. Evaporation from the spray would be expected to follow the general laws governing evaporation for the wet bulb of a psychrometer in that the rate of evaporation would be governed by the rate of sensible heat transfer to the falling droplet. Thus, the water droplet from a sprinkler should approach the wet bulb temperature of the air regardless of the initial water temperature. Experimental data obtained at Twin Falls, Idaho, support this theory. Water delivered to a sprinkler at 41, 63, and 96°F. reached temperatures of 50, 51, and 54°F., respectively, by the time it reached the crop. The wet bulb temperature was 50.5°F. and the air temperature was 60°F. This characteristic of sprinkler irrigation may be highly significant when irrigating crops at some stages of growth when wet bulb temperatures are low. The results of these studies also confirm the fundamental basis being established to develop more reliable procedures for estimating evaporation losses during sprinkler irrigation. (SWC 5-f2)

In a PL-480-supported study at the Technion Research and Development Foundation, Haifa, Israel, the measured evaporation losses during sprinkler application were found to be far less than commonly assumed for the semi-arid conditions of that country. The maximum net loss under daytime irrigation was 10 percent of applied water. In a laboratory study of the effect of sprinkler drops on soil compaction, crusting and infiltration, the most important characteristic of drops was their impact velocity. Intensity of application was next in importance. The drop size was of importance on the loess soil even when impact velocity was low. (A10-SWC-5)

In a PL-480-supported study at Hebrew University, Rehovot, Israel, low-intensity sprinkler irrigation (4.5 mm./hr.) resulted in 14, 26, and 25 percent greater production of celery, parsley, and green peppers than with high-intensity irrigation (13 mm./hr.). In another phase of the study there was an increase in microbial development with low-intensity irrigation on the finer textured soils, but not on the sandy soils. This has not been related to yield or other crop effects. (A10-SWC-19)

Water applied at frequent intervals through the day as mist on the foliage of cotton at Thorsby, Alabama, and tomatoes at Watkinsville, Georgia, reduced the leaf temperature 2 to 4° C. but had no effect on soil temperature during July and August. Insect and disease problems associated with the more humid atmosphere inherent with this treatment more than offset any benefits from the cooling effects. (SWC 5-b1)

3. Subsurface irrigation techniques and equipment. At Riverside, California, a variety of devices designed to apply irrigation water below the soil surface are under study. One system utilizes sections of porous ceramic pipe to provide transfer from a plastic supply line to the soil. Others utilize plastic pipe specially fabricated or bored to allow exit of water from the sides of the pipe to the soil. All systems are installed approximately 12 inches below the soil surface. Objective of the study is to determine if such subterranean irrigation systems can be used to conserve water supplies by decreasing surface evaporation losses associated with surface irrigation methods. Preliminary results show that citrus trees, the only crop presently under study, can be irrigated adequately by this method. Newly planted citrus trees have been grown for two irrigated seasons. Full-grown trees produced as well as adjacent trees irrigated by conventional surface methods. The study is continuing in order to assess salt accumulation, moisture movement, clogging of systems or other operational problems that may develop. (SWC 5-8(g1) Rev.)

Subirrigation of turf with porous tile has been under study at Ft. Lauderdale, Florida, for several years. The tile installed in Arzell fine sand became so clogged within several weeks after installation that insufficient water was supplied to a sod of bermudagrass. Laboratory study showed the nature of the inorganic and bacterial deposits and led to the development of remedial measures. Treating the tile periodically with hydroxyacetic acid to prevent inorganic deposits and with sodium hypochlorite to prevent bacterial growth has maintained an adequate flow rate through the tile. (SWC 5-b1)

C. Systems Design for Efficient Use of Water and of Labor

1. Irrigation system efficiency. The overall irrigation efficiency of a project is affected by seepage losses in the project's main canal and laterals. Seepage losses must be predicted before an irrigation project is constructed, to arrive at diversion requirements, channel sizes, and an appraisal of the need to include channel linings during the initial construction phase. A joint comprehensive USBR-ARS study of the disposition of irrigation water in a relatively new irrigation project near Twin Falls, Idaho, requires the assessment of seepage losses as they exist, and thereby provides the opportunity to evaluate methods of determining seepage rates. Ponding tests in the upper one-half-mile section of a 1-mile reach indicated seepage rates of 0.50 foot per day as compared with 0.65 foot per day for the lower one-half mile section. Inflow-outflow measurements over a 4-mile length, which included the above 1-mile reach, gave consistent losses varying from 0.90 to 0.95 foot per day. In the upper ponding section, 72 seepage meter tests made using seepage meters developed at Phoenix, Arizona, measured losses ranging from 0.14 to 2.65 feet per day with an average value of 0.65 foot per day. The seepage meter tests were made with the water depth at 2.0 feet. When projected to an operating depth of approximately 5½ feet, the seepage rate would be higher. The results of the seepage meter method and ponding

tests showed less variation than is often found in such comparisons. The losses indicated by the inflow-outflow measurements are in the range of 3 to 6 percent of the total flow and, therefore, would be subject to flow measurement errors that would be reflected in the seepage measurements made by this method. (SWC 5-f2)

In the Escalante Valley, near Milford, Utah, irrigation efficiency decreased slightly during the period 1961-1964. A greater percentage of the area was planted to alfalfa during this period. An increase in the number of farms attaining near-average irrigation efficiencies was noted between 1961 and 1964. For prevailing water supply and cropping conditions in the area, irrigation efficiencies near 60 percent may be reasonably expected. Alfalfa and potatoes showed net per-acre returns of $27.67 and $70.84, respectively. All other crops included had negative net returns. The economic pumping lift under present cropping conditions was computed to be 249 feet. At a water table decline rate of 2 feet per year, this level would be reached in 82 years. (SWC 5-8(g1) Rev.)

2. Automation. A large percentage of the irrigated lands in the United States and throughout the world have open channel water distribution systems. One method of increasing the irrigation efficiency of these systems is to provide for automatic control of irrigation water. With automatic controls the farmer can adjust the duration of irrigation sets to the time needed to apply adequate amounts of water instead of irrigating according to labor availability and other farming schedules. Three new general types of automatic check structures have been developed and successfully tested at Twin Falls, Idaho. They include: (1) Portable and semipermanent drawstring-type flexible check dams for both lined and unlined ditches; (2) a metal flap gate mounted on a commercial cutoff wall or bulkhead; and (3) adjustable gates to control water level in lined ditches. These structures are adaptable to existing open channels distribution systems and the common methods of distributing water over the fields, and are easily serviced and maintained by the farmer. The drawstring-type checks and the flap gate can be float- or timer-operated, or operated by an electrical signal from an automatic programmer, soil moisture sensor, or a manual electrical device. (SWC 5-f2)

Progress in development of automated surface irrigation systems utilizing inflatable butyl rubber valves, at Fort Collins, Colorado, relates to improvements in remote control telemetry equipment. The transmitter is now designed with electronic timers capable of sequencing water control valves for timed intervals ranging from 5 minutes to 16 hours. Or, if the farmer prefers, it is possible to bypass the timer if sensors such as electrical resistance blocks or tensiometers are used. For example, valves on alfalfa risers or in farm ditch turnouts could be opened or closed by the sensor when surface water reaches a predetermined point of advance down the border strip or when soil water penetrates to a predetermined depth at the desired location within the irrigation run.

The cost of the redesigned telemetry system has been reduced at least 50 percent by selection of alternative but equally reliable components and by redesign of circuits. In another development, modification of the inflatable valve for alfalfa risers permits the use of hydrants and gated pipe where closed distribution systems are used. (SWC 5-d1)

A small tractor-type field irrigator capable of steering itself while slowly dragging a canvas check dam in a contour ditch for irrigating side slopes has been field tested at Grand Junction, Colorado, and at the Seedskadee Development Farm in west-central Wyoming. Flowing water checked behind the canvas dam overflows the ditch bank to irrigate an area below the ditch. Variable tractor speed allows adjustment for stream size, grade and length of irrigation run. Under ideal conditions the mechanical irrigator performs reasonably well, but under adverse conditions of ditch grade and width, cobblestones, and nonstable ditch banks, the machine lacks versatility. An auger pump fitted to the tractor and powered by the same engine as is used to propel the tractor allows operation in newly formed ditches with erodible banks. This development has increased operation capabilities, but further field testing is required to assess pump operation efficiency, labor-saving potential and overall improvement in water use. (SWC 5-d1)

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AREA 6: DRAINAGE PRINCIPLES, REQUIREMENTS, PRACTICES, AND FACILITIES FOR PROTECTION OF CROPS AND SOILS

Problem: Excess water is the dominant hazard to 245,563,000 acres or 17 percent of the land in the United States.1/ For the cropland area, excess water is the dominant problem on 59,906,000 acres or 14 percent. Water management systems have been applied to some 140,000,000 acres of potentially wetland in the United States. More than 90,000,000 acres are in organized districts and the remainder are individual farm enterprises. More than 60 percent of the acreage in organized districts is in seven Corn Belt States. The U.S. Census Report for 1960 shows an expenditure during the last ten years for new drainage work of nearly $186,000,000 and a cost of maintenance, operation, and repair of more than $231,000,000.

There are numerous water management problems on these lands. High water tables during the spring restrict root development, which lowers the plants' drought resistance during the dry periods that generally follow. Water ponded in microtopographic depressions delays plantings beyond optimum dates, and makes the use of modern high-speed farming equipment uneconomical. Hillside seep areas function similarly to reduce farming efficiency. Conventional methods of subsurface drainage are costly. Drainage design is generally based on empirically determined drainage coefficients instead of precisely developed drainage or aeration requirements of specific crops.

The economic success and feasibility of many irrigation projects depend on adequate subsurface drainage to prevent salting out and abandonment of the projects. On more than 50 percent of the irrigated acreage in the 17 western States, or more than 15,000,000 acres, drainage is a necessary complement for successful operation.

USDA AND COOPERATIVE PROGRAM

The Division conducts both basic and applied research and development in the area of land drainage, utilizing agricultural and hydraulic engineers, soil physicists, and plant physiologists at various physiographic area research centers and field stations throughout the United States. The scientific and engineering effort in this area totals 17.5 professional man-years. Of this total, 0.8 are devoted to surface and open ditch drainage; 4.9 to subsurface conduit drainage--new materials, hydraulics, installation equipment and techniques; and chemical and biological clogging of tile; 2.8 to drainage for salinity control; and 9.0 to design of optimum

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1/ U.S. Department of Agriculture, Agriculture Information Bulletin 262,1962.

systems--drainage requirements of plants; soil properties, hydraulic conductivity and other factors related to drainage, and systems performance--flat and sloping lands.

PROGRAM OF STATE EXPERIMENT STATIONS

A total of 17 scientific man-years is devoted to this area of research.

PROGRESS -- USDA AND COOPERATIVE PROGRAMS

A. Surface and Open Ditch Drainage

1. Landforming, cut-fill effects and remedial measures. At Blacksburg, Virginia, marked variations in hydraulic conductivity and water-retention characteristics were obtained for subsoils and topsoils of the Cecil and Appling series. Hydraulic conductivity was not directly correlated with the silt plus clay content of the material. Preliminary studies indicated aeration would not necessarily be a critical factor for plant growth on these subsoils. (SWC 6-a1)

Landforming of sloping tobacco land in Virginia for better water management has shown little or no detrimental effects on yields over a four-year period. Differences in yield where topsoil had been stockpiled and replaced were only 215 pounds per acre greater than where standard cut and fill procedures were used, with a quality difference of only 2 cents per pound. Results obtained over the four years indicate landforming on sloping lands of the Cecil and Appling series will not appreciably affect yields if the soils are adequately fertilized and adequate levels of soil water are maintained. (SWC 6-a1)

2. Row grade and length effects. Preliminary analyses of surface runoff data at Baton Rouge, Louisiana indicate that row length and row grade both affect peak rates of runoff, but only row grade affects the amount of runoff from high-intensity rainstorms on precision-graded rows in the Mississippi Delta. These relationships are expressed by the formulae $Y_r = 0.961 + 4.911X_1 - 0.00084X_2$, where Y_r is peak rate of runoff, X_1 is row grade, and X_2 is row length; and $Y_a = 0.709 + 2.217X$, where Y_a is amount of runoff, and X_1 is row grade. Yield of corn for silage was not related to row grades or to row lengths represented in the study in 1965 when rainfall was 6.8 inches below normal for June, July, and August. (SWC 6-b2)

B. Subsurface Conduit Drainage

1. New materials--laboratory and field tests of performance. The amount of support given to a pipe by the soil affects the load that nonrigid conduits will carry. At Columbus, Ohio, a method has been developed for solving equations for predicting deflection and structural strength of flexible tubes under various soil loads. Empirical laboratory measurement

of a soil modulus has been used advantageously along with a trial-and-error method using a digital computer for obtaining satisfactory solutions of the equations. This combined theoretical-empirical approach makes it possible to predict more accurately the actual load-carrying capacity of flexible tubes. Thus, design capability for low-cost flexible drainage conduits is considerably improved.

The creep characteristic (continued deflection under a steady load) of plastic materials has a very important bearing on the load-supporting properties of drain tubes. Materials with little or no creep resistance may be classed as unsuitable for drainage conduits as used in agriculture. In Ohio, the creep characteristics of various types of plastic tubes were evaluated. The creep resistance of low-density polyethylene, high-density polyethylene, and polyvinyl-chloride plastics is poor, good and excellent, respectively. The creep resistance of expanded polystyrene plastic tubes depends on the magnitude of the stress in the pipe wall. At stress values above the compressive yield stress, the tube continues to deflect (creep) until it fails. Thus, there is a critical loading that must be considered in the design of drainage conduits where the expanded polystyrene material is used. (SWC 6-c1)

At Logan, Utah, relative load-bearing strengths were determined for a number of conduit materials using a flexible load cell. All materials tested except the 3-inch-diameter polyvinyl chloride showed higher load-bearing capacity than the standard 4-inch concrete drain tile. These materials included 4-inch-diameter enameled steel, 18- and 28-gage semi-circular galvanized steel, 4-inch-diameter semiridged polyethylene, 3-inch diameter polyvinyl chloride, 2-inch-diameter "filter flex," and standard 4-inch concrete drain tile. In conduit flow tests made on these materials, the 28-gage semicircular galvanized steel conduit registered the highest flow rate. (SWC 6-g2)

In the design of subsurface drainage systems, resistance coefficients (Manning's "n") for various sizes and capacities of drainage conduits must be known. Although "n" values are available for the common pipe materials, information is lacking on the extent that the "n" value changes due to excessive gaps and misalignment during installation. Information is also lacking on the newer plastic pipe drainage materials. Studies at Fort Collins, Colorado, have shown that Manning's "n" for various lengths and diameters (4 and 6 inches) of clay and concrete pipe with plain ends properly aligned were essentially the same as those being used for design purposes by the Soil Conservation Service and the U.S. Bureau of Reclamation. Joints offset 1/2 inch increased the "n" value and in one instance reduced flow capacity by 33 percent. Corrugated plastic pipe (3-inch diameter) had an "n" value of 0.017, indicating even higher flow resistance than observed for "poorly laid" tile. (SWC 6-d1)

In Ohio, results from a 5-year study have shown that a zippered mole liner made of 0.015-inch PVC sheet plastic does not provide adequate

structural strength. Zippered mole liners installed in heavy clay soil at a minimum depth of 30 inches were not damaged by moderately deep plowing operations. However, they were quite severely deformed by soil loads during prolonged wet periods. Structural failure of the liners was propagated in both directions from localized deformations that occurred at the time of installation from either alignment changes (both vertical and horizontal) or nonuniform closure of the soil slit opening and/or nonuniform recompaction of the soil above the liner. An effective life of about 4 to 5 years is indicated for the thin plastic mole liners under soil conditions similar to those of this study. It may serve effectively for drainage where material and installation costs can be justified in light of this life expectancy. (SWC 6-c1)

At Logan, Utah, it was found that thin-walled plastic mole drain liners also lack sufficient strength to prevent localized failure under irrigation. Although some sections of the zipper-fastened plastic mole drains installed in 1963 remain in good condition, the majority show signs of deformation and collapse. Localized failure has been attributed to unusual localized loading (passage of farm machines) or saturation of the soil profile above the drains or both. Conversely, the agricultural production on the mole-drained plots was exceptional when compared to the undrained plots and if sustained over a 6-year period, may offset their cost. (SWC 6-g2)

At Brawley, California, laboratory tests completed in 1965, showed that glass fiber mat is an effective soil filter. Few soil particles larger than 0.074 mm. would move through any of the three mats tested. Tank tests to compare the performance of gravel, glass fiber mat, and glass fiber sheet filters under the same soil and filter geometry established general trends, although the data were quite variable. Outflow rates will usually be greater from a gravel-filtered drainage system than from either a glass fiber mat- or glass fiber sheet-filtered system, and, generally, the glass fiber mat will produce a greater outflow rate than the glass fiber sheet. (SWC 6-g2)

A meter to determine the inflow capability of tile joints *in situ* was developed and field tested at Brawley, California, during 1965. The meter is fastened to a tile lateral, astride a joint, and the effective uniform gap width for the joint is obtained by measuring the rate of fall of water in the meter. The meter is useful for diagnosing tile drain system problems, and evaluating chemical means for restoring the performance of systems with chemically clogged joints. (SWC 6-g2)

At Brawley, California, a comprehensive new research investigation has been inaugurated on an 80-acre tract of land to evaluate tile drain performance, develop improved procedures for reclamation, and prescribe economical and feasible methods of maintaining drainage systems. More than 10,000 miles of tile drains have been installed in the Imperial Valley to protect 300,000 acres of highly productive or potentially productive land. The investment, both private and governmental, is estimated to be about $21,000,000. (SWC 6-g2)

2. Installation equipment and techniques. In Ohio, tests were conducted on the use of a newly developed hollow-bladed tool, pulled behind a tool-bar-mounted mole plow, for installing thin-walled preformed corrugated plastic tubing in a mole-drain channel. The corrugated tubing has considerable longitudinal flexibility, which gives it very good handling and installation characteristics, and has exceptionally good radial structural strength for supporting soil and other loads. The 2¼-inch corrugated tubing fed into and through the installation tool exceptionally well. The draft required and the soil eruption during installation in a silt loam soil were both only slightly greater than that for the thin-bladed mole-lining tool used for installing sheet plastic liners. The 3-inch-wide slit in the soil was effectively closed to the full 30-inch depth of the plastic drain by two passes of the crawler tractor. Because of the radial structural strength imparted to the tube by the corrugations, the amount of material required per unit length of tube is less than for a smooth-walled pipe of comparable strength. Since the cost of plastic tubing is essentially proportional to the amount of material used in fabrication, this tubing appears to have considerable potential as an effective low-cost drainage conduit. (SWC 6-c1)

3. Chemical and biological clogging of tile. At Brawley, California, tile line inspections indicate that the tile sealing and clogging problem is not limited to any particular soil type or area of the Imperial Valley. The reduction-oxygen potentials of soils at 25 field locations are now under investigation in the laboratory. Data obtained from ground-water surveys indicate that the redox potentials of the ground water do not change greatly as a result of seasonal changes and that, generally, the ground waters have relatively low concentrations of iron and manganese. (SWC 6-g2)

C. Drainage for Salinity Control

At Grand Forks, North Dakota, a combination landforming and tile drainage study to control salt content on moderately saline Glyndon silty clay loam indicates that the area of influence of a tile drain extends beyond 300 feet. Salinity of tile effluent increased as the season progressed. However, flow from tile lines during the summer months of 1965 was greater than usual because of above-normal precipitation and fallowing of plots. On the basis of 5 years' results, the economics of tile drainage on moderately affected saline soils in the Red River Valley remain questionable, since outflow from tile occurred infrequently during 4 of those years. (SWC 6-d1)

Tank studies were started in 1964 at Norfolk, Virginia, to determine the drainage requirements of economic plants under saline soil conditions as may develop in the Atlantic Coastal Flatwoods soils area and to relate these requirements to factors such as soil texture, aeration, soil density, etc. In the first phase of the study which was concerned with the rate of salinization of the soil from saline water tables, the salinization rate of a Rumford loamy sand, the coarsest textured of the three soils studied,

was less than that of an Othello loam and an Othello silty clay loam. The water tables were established in soil columns at 6, 12, 18, 24 and 30 inches after flushing and draining. Movement of salts and water upward was due to surface evaporation only. There were no significant changes in soil water gradient within the columns throughout the study. The rate of salinization was proportional to the rate of evaporation. Rate of evaporation decreased as soil texture became coarser and as depth to water table increased. Saline gradients were steeper in the two Othello soils than in the Rumford and were steeper for the deeper water tables than for the shallow ones. (SWC 6-a1)

D. Design of Optimum Drainage Systems

1. Drainage requirements of plants. A more thorough understanding is needed of the effects on root behavior of limited soil aeration caused by excess moisture. Such knowledge can then be used to determine the degree of drainage needed to provide the proper environment for root growth, nutrient uptake, and gaseous exchanges necessary for optimum plant growth.

Studies at Raleigh, North Carolina, showed that intact root systems grown in a mist spray responded quickly and characteristically to different gaseous mixtures. Cell division of root tips was inhibited within 15 minutes by a spray of pure nitrogen, and was reduced to 50 percent of normal after 4 hours of this treatment. Restoration of oxygen by applying air after 4 hours permitted the cell division rate to return to normal within 18 hours. The cell division rate stopped completely when there was no oxygen for 24 hours, and was restored to only 60 percent of normal after 48 hours in air. When as little as 2.5 percent oxygen was mixed with the nitrogen, cell division was still 30 percent of normal after 24 hours of treatment, and returned to normal within 6 hours in air. Some root tips were killed by pure nitrogen, but a new meristematic area developed 6 to 8 mm. behind the tip, and growth was resumed from this new tissue. Cell division was reduced 75 percent within an hour and stopped completed within 12 hours with 1 percent oxygen, 20 percent CO_2, and 79 percent N. Only slight recovery occurred after 48 hours in air. The CO_2 was more toxic also to root tips than N, but small amounts of oxygen in the mixture were beneficial to primordia within the primary root.

Other preliminary findings in these studies suggest that roots of different types of plants, such as corn and string beans, consume oxygen at the same rate per unit weight of roots when supplied with adequate oxygen, but the critical oxygen level varies between species. This probably is due to differences in root morphology. These studies are continuing. (SWC 6-b1)

At Weslaco, Texas, tolerance of 3-, 6-, and 9-week old carrot plants to 1, 2, and 3 days of flooding by ponding water on the soil surface was determined. Up to 63 percent of 3-week-old carrots were killed by 3 days of flooding, whereas all 9-week-old plants survived this period of flooding.

All measures of carrot growth at harvest were significantly affected by duration of flooding, but most of the effects could be attributed to the consequences of the reduction in plant population by the first 3-day flooding. The oxygen content of the soil atmosphere was reduced by flooding, but not enough to cause as much damage to young carrots as was observed. (SWC 6-12(e3))

Greenhouse studies at Norfolk, Virginia, show that adverse effects of poor drainage on the growth of corn can be alleviated by nitrogen fertilization. The effects of 0, 100, and 200 lbs. N per acre from sodium nitrate and ammonium sulfate, were evaluated in a pot study at three soil water conditions: field capacity, a water table at the 6-inch depth, and one at the 2-inch depth. At field capacity, corn yields increased for both levels and both sources of nitrogen. Yields decreased with the 2- and 6-inch water tables for the no nitrogen and the sodium nitrate-fertilized plants. A very great reduction occurred on the high nitrate treatment. For the ammonium-fertilized corn grown with a 6-inch water table, yield was greater than for that grown at field capacity. Water-use efficiency decreased with nitrate fertilization and increased with ammonium fertilization on waterlogged soils. The study is continuing. (SWC 6-a1)

2. Soil properties, hydraulic conductivity and other factors related to drainage. At Columbus, Ohio, *in situ* measurements of hydraulic conductivity of a Miami silt loam showed that the time allowed for drainage after removal of ponded water had a significant effect on the conductivity when the soil was again ponded. Conductivity after short drainage periods (2 to 10 hours) was only one-half that obtained after a drainage period of 1 to 2 days. This difference is attributed to differences in air entrapment upon reponding. This information has application not only for drainage of agricultural lands but in ground-water recharge operations where periods of ponding and time of drainage are both variable but are subject to control. (SWC 6-c1)

At Fleming, Georgia, variations in the magnitude of hydraulic conductivity measurements made by horizons on 10 different soils of the Atlantic Coast Flatwoods land resource area were not explained adequately by soil texture, organic matter, available water capacity, or bulk density of the soils. Soil series and type also were not good indicators of soil drainability. (SWC 6-b2)

3. Systems performance--flat and sloping lands. Combinations of tile and diversion terrace drainage being studied on a wet, seepy, sloping Cabot silt loam at East Franklin, Vermont, showed that the volume of discharge appears to be related primarily to the total footage of drains. The end of drain flow in the spring and the start in the fall appears to bear a definite relation to the beginning and end of crop growth. Diversion spacing did not affect alfalfa yields, but yields did increase with increasing degree of tile drainage on the second cutting. For this cutting, the percent alfalfa in the harvested hay was 75 percent for the 100-foot

tile spacing, 66 percent for the 200-foot, and 61 percent for no tile drainage. The remainder was grass. (SWC 6-a1)

With 55 inches of rainfall in 12 months at Fort Lauderdale, Florida, it was necessary to drain 38, 39, 40, and 45 inches of rainwater from full-, 2/3-, 1/3-, and 0-sod cover, respectively, to keep a water table from rising above 24 inches. (SWC 6-b1)

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AREA 7: SALINE, SODIC, AND RELATED SOILS PROBLEMS, AND QUALITY OF IRRIGATION WATERS AND THEIR RELATION TO PLANT GROWTH PROCESSES

Problem. Salinity is a continuing and major problem in irrigated agriculture. In the arid West, injurious concentrations of salts in the soil have impaired the use of 25 percent of the irrigated land. Fifty percent of this area is endangered. Salinity or brackish water problems in the eastern seaboard area have increased with the rapid expansion of supplemental irrigation in this area where tidal streams and creeks are a conveniently available source. Soil salinity problems exist in many dryland farming areas in semiarid regions.

Salts move upward in the soil with water to supply evapotranspiration requirements and are left behind as the moisture passes to the atmosphere. This results in injurious accumulations in the root zone unless excess water as rain or overirrigation is periodically passed downward to leach the salts to the ground water or to a tile drainage system for removal in the tile effluent. These salts generally come from the irrigation water, although some soils naturally contain excessive quantities of harmful salts. The nature of the salts, soil, and climatic conditions and leaching water quality create complicated problems, many of which have not been solved. The use of salt-tolerant plants offers relief, but these plants must be identified and developed. Disposal of leached out salts without degrading water quality for the downstream user is a critical problem.

USDA AND COOPERATIVE PROGRAM

The Division conducts both basic and applied research in the area of saline and sodic soils and quality of irrigation water for the growth and production of agricultural crops and ornamental plants. Scientists involved in this research include physicists, chemists, soil scientists, plant physiologists, agronomists, and agricultural engineers. The center for basic research in this area is the U. S. Salinity Laboratory, Riverside, California. Brackish water studies for the Atlantic Coast flatwood resource areas are centered at Norfolk, Virginia. Salinity problems of the Rio Grande Plain and Lower Valley areas are under study at Weslaco, Texas; of the Red River Valley at Mandan and Grand Forks, North Dakota; and of the Snake River Valley at Twin Falls, Idaho. In addition, four PL-480 studies are underway in Israel.

The scientific and engineering effort in this area totals 22.1 professional man-years per year, nearly two-thirds of which is at the U. S. Salinity Laboratory. Of the total professional man-years, 5.4 are devoted to mechanisms of reactions, soil properties, diagnosis and soil-water-plant systems; 7.1 to physiological basis for plant tolerance, adaptation and response to plants; 2.3 to water composition, ground water and salt balance; 3.5 to water, soil and crop management systems for saline and sodic soils; 2.2 to leaching processes; and 1.6 to spectral reconnaissance for diagnosis of soil and water management problems.

PROGRAM OF STATE EXPERIMENT STATIONS

A total of 5 scientific man-years is devoted to this research.

PROGRESS -- USDA AND COOPERATIVE PROGRAMS

A. Mechanisms of Reactions, Soil Properties, Diagnosis and the Soil-Water-Plant Systems

1. Mechanisms of reactions between dissolved, and absorbed constituents of salt-affected soils. In connection with a study at Riverside, California, on the origin, concentration, and precipitation of salts during the genesis of soil-salt deposits, it has become necessary to obtain an analytical means for predicting the sequential precipitation of salts from concentrated salt solutions. Attempts to use the extended Debye-Huckel theory for this purpose failed, but a satisfactory solution was the development of expressions describing the apparent solubility product of different salt species as a function of both the total salt concentration, or, more correctly, the ionic strength, and the concentration of specific ions present in the solution. Data for 560 concentrated mixed-salt solutions have been analyzed, resulting in expressions for the apparent solubility products of 28 simple and compound salts derived therefrom. In addition, an analytical approach for predicting the densities of concentrated mixed-salt solutions was developed.

Particle surface area and cation-exchange-capacity are fundamental soil properties that have major implications in salinity work, but present methods for measuring these properties are unsatisfactory. At Riverside, California, it was found that Cl^- repulsion by arid-zone soils from a solution having a high and uniform concentration of Cl^- correlates closely with a surface area as measured by the standard ethylene glycol method. Using this information, a measurement of Cl^- repulsion has been incorporated into the standard sodium acetate method for determining cation-exchange-capacity with the result that values for surface areas as well as cation-exchange-capacity are obtained with little additional analytical work. (SWC 7-gF1)

2. Structure, organic matter, and microbial relations in salt-affected soils. At Riverside, California, when soils containing swelling clays were subjected to different mixed-salt solutions their hydraulic conductivity (HC) was found to be well correlated (r = 0.943 to -0.973) with the macroscopic swelling of pads of extracted soil-clay in these same solutions. Selling in most cases was largely irreversible, because of a gel structure in the water-clay systems; hence, reversibility of HC decreases can no longer be used as an index of the relative contributions of swelling and and dispersion in producing such decreases. These two results suggest that clay swelling may be considerably more important in producing HC decreases under high sodium-salt conditions than has been previously thought.

The macroscopic swelling of pads of extracted soil-clay in mixed-salt solutions has been predicted from the mineralogical composition of the clay, by assuming that demixing of ions in the system yields discrete regions of essentially homoionic clay. It has thus been possible, after calibrating a given soil by obtaining a few values for relative HC as a function of solution composition, to predict relative HC when the soil is subjected to any other mixed-salt solutions. Experimental verification of ion demixing in clay interlayers is being sought by a low-angle X-ray diffraction technique, since chemical analyses have suggested that demixing does not occur through a preferential accumulation of one type of ion in interlayer positions and of another type on external mineral surfaces.

At Riverside, California, also, the effect of soil texture on HC decreases has been assessed for ten soils of constant clay mineralogy (40% montmorillonite) from the Imperial Valley of California. Multiple regression analysis of data for flow of NaCl solutions through the soils yielded a multiple correlation coefficient of 0.929 between percent clay, electrolyte concentration, and HC, with approximately 90% of the regression attributable to electrolyte concentration, and 10% to percent clay. Relative HC values at a NaCl concentration of 200 meq./l. were 0.83, 0.35, and 0.03 for samples with 5, 15, and 45% clay respectively; comparable values at 50 meq./l. were 0.35, 0.01, and 0.00. Relative HC under high sodium-low salt conditions was thus highly dependent on the total amount, as well as the type, of soil-clays present. (SWC 7-gF2)

3. Methods for the diagnosis and study of salinity in soils and water. Because automatic recording of physical measurements is usually desirable, a graphical recorder for a pan evaporimeter was developed at Riverside, California. Water from a reservoir is pumped at a steady rate to the pan in which a device maintains a constant level, and the excess water is returned to the reservoir by gravity flow. Change in level of the water in the reservoir represents the difference between evaporation from the pan and precipitation. The record is made on a vertical cylindrical chart by a pen having direct coupling to a float in the reservoir. Recording amplification is determined by the pan-to-reservoir area ratio. In the present model, amplification values of 2 and 5 are selectable by a cock that controls a tubular bypass between concentric reservoirs. (SWC 7-gF3)

An accurate method for determining ammonia concentration by electrical conductivity has been developed at Riverside, California. The method also is suitable for determining total nitrogen after Kjeldahl digestion or for nitrate-nitrogen after reduction with Devarda alloy. The ammonia is distilled into boric acid, the distillate made to volume, and the electrical conductivity determined. The ammonia concentration is read from a graph relating concentration to electrical conductivity. An important feature of the method is the extraordinarily wide range of ammonia concentrations that can be determined. Standards from ammonia distillation, and from Kjeldahl digestions of ammonium salts and various amino acids all fitted the same calibration curve with a standard deviation of only 0.25 percent. Determination of total nitrogen on plant samples by this method after micro-Kjeldahl digestion was found to be as accurate and precise as the standard macro determination. (SWC 7-gF3)

4. The soil-water-plant systems under saline conditions. A complete understanding of water movement and availability to plants requires a quantitative knowledge of the transpiration and the deep percolation. To measure these factors seven soil columns have been instrumented in the greenhouse at Riverside, california. Two of these are 250 cm. long and the other 5 are between 120 and 180 cm. long. Transpiration rates of the pepper plant growing in each column were obtained by weighing the entire column. These data indicate that it should be possible to ascertain whether water is moving upward or downward at the bottom of the root zone from hydraulic head measurements made just below the root zone. On the basis of these data, a concept of salt accumulation and movement is being developed which, it is anticipated, will lead to a more rational basis for evaluating and controlling salinity. A critical analysis of the field capacity concept has been made and a system for estimating the field water content after irrigation from the soil water diffusivity has been developed. (SWC 7-gF4)

A psychrometer that minimizes the dependence of the psychrometer reading on temperature has been developed at Riverside, California. As a result, psychrometers are now available for measuring the total water potential of soils in situ. Such psychrometers in a soil column in the greenhouse are yielding water potential measurements with an accuracy of ± 0.5 bar in the presence of temperature fluctuations as large as 5° C. per day. Attempts are being made to measure water potential within living plant tissue with the same accuracy, but so far it appears that such measurements will be restricted to hollow tissues such as onion leaves and pepper fruits because of the necessity for the sample to completely surround the thermocouple. The successful development and testing of this instrument under rather rigorous conditions represents an extremely significant advance. (SWC 7-gF4)

B. Physiological Basis for Plant Tolerance, Adaptation and Response of Plants

1. Tolerance of plants to salinity--arid area. Previous studies at Riverside, California, showed that the sugarcane varieties N. Co. 293 and 310 and the Hawaiian variety H50-7209 are relatively sensitive to salinity. Yields decreased by 10 percent for all three varieties at about 3 mmhos./cm. EC_e. A second year's harvest of the N. Co. varieties from the field plot experiment revealed that the ratoon crop was only about half as salt-tolerant as the seed crop. However, a ratoon crop of H50-7209 in the greenhouse did not show this increase in salt sensitivity. It is postulated that the low winter temperatures in the field were responsible for the decrease in salt tolerance. Although moderate salinity under favorable environmental conditions decreased sucrose content of the cane, reduction in cane weight was four times more important in reducing sugar yields than was the decrease in sugar percentage. In greenhouse cultures, salinity affected all growth parameters, number, length, and diameter of canes, whereas in the field plots, length alone was affected. The greater salt tolerance of N. Co. 293 as compared with that of N. Co. 310 at moderate salinities was related in both greenhouse and field plots to a smaller inhibition of internode length and, therefore, of cane elongation. Accumulation of sodium in sugarcane was low and was restricted to the basal internodes. Salinity increased potassium content of the cane much more than sodium content. (SWC 7-gF5)

At Riverside, California, research on interactions between soil fertility levels and salt tolerance has shown that sweet corn yields with high-N at all salinity levels were about twice those on the low-N series, and the effect on relative growth for each increment of salinity was similar for high- and the low-N treatments. All plots received equal and adequate levels of P and K. One series of three plots adjusted to graded salinity levels received high levels of $Ca(NO_3)_2$ added to the irrigation water, equivalent to 231 lb. N/acre. The other series received a total of only 42 lb. N/acre. Previous observations on Bermudagrass had indicated a leveling-out of salinity effects when low levels of N fertilizer were applied, but with sweet corn, the relative decrease in growth was essentially unaffected by level of N fertilization. (SWC 7-gF9)

Lysimeter studies at Weslaco, Texas, showed that carrot yields were not affected by soil salinity in the range of EC_e values 2 to 8 mmhos./cm. However, carrots withstood flooding better at the highest salt level. (SWC 7-e1)

2. Tolerance of plants to salinity--humid area. Field studies at Norfolk, Virginia, show that crops vary in their retention of salts from saline sprinkler irrigations. Plants were sprinkler irrigated with dilutions of synthetic sea water ranging from 0 to 100 percent of sea water strength. Two days after irrigation with full-strength sea water, the following amounts of salt were retained on the leaves (cl./cm.^{2}): corn, 125; beans, 623; tomatoes, 1107; and peppers, 2393. The amount of salt retained varied not only with crops, but with length of irrigation and existing climatic conditions. Moderate to severe leaf injury was noted on the crops at full-strength sea water. Only slight injury was observed at 50-percent strength. Significant reduction in yields was obtained only where 50-percent and full-strength sea water was used. (SWC 7-a1)

3. Physiological basis for plant tolerance to saline soils and water. A reduction in the rate of water uptake by roots and a decrease in the water content of the shoot are among the first detectable plant responses to salinity. Studies at Riverside, California, with intact bean and cotton plants have shown that a humid atmosphere reduced or prevented the depressing effect of NaCl salinity on both water content and growth of the shoot. At the same time, it actually increased the amount of chloride/unit dry matter in bean shoots and the amount of sodium and chloride/unit dry matter in cotton shoots which shows that the accumulation of these ions in the shoot per se was not responsible for the suppression of growth. Under the conditions of these experiments, suppressed shoot growth seemed to be caused by a decreased rate of water movement from the roots. When this was compensated for by decreasing the rate of water loss from the shoot, the growth suppression was relieved.

An attempt was made to separate the effect of NaCl on the uptake of water by roots from its effect on the growth of the shoot. Bean plants were allowed to develop until the leaves on the main axis had matured before salinizing the cultures with 48 meq. NaCl/l. Additional leaf development was prevented by removing the axillary buds. Thus, the leaf area per plant remained constant. Salination was carried out at the beginning of a 12-hour dark period, at which time there was no wilting or other visible sign of injury. Salination caused an immediate reduction in the rate of water uptake which persisted for at least one week, or long past the time required for the roots to complete osmotic adjustment. Further, the plants failed to resume water uptake at the presalination rate one week after they had been returned to NaCl-free nutrient solution. The NaCl caused some irreversible change in the roots which impaired water uptake. Evidence has now been obtained that this change involves a loss from the root to the solution of protein, polysaccharide, polygalacturonic acid, and lipid materials apparently of wall origin. There was no detectable loss of free amino acid and and reducing sugar, indicating the absence of any general leaking of intracellular constituents as occurs, for example, when roots are frozen, The release of certain wall constituents to a saline solution is to be expected on the basis of recent evidence concerning the influence of inorganic ions on the solvent properties of water. (SWC 7-gF6)

At Riverside, California, an experiment was conducted to determine the absorption and translocation of radioactive sodium in bean plants containing varying concentrations of non-radioactive sodium. The results indicated no statistically significant effect of initial sodium concentration on the amount of radioactive sodium subsequently absorbed by the plant or translocated to the shoot in the presence or absence of DNP, a metabolic inhibitor. However, DNP decreased root concentration of radioactive sodium and increased percent translocation into the shoots. Differences in sodium concentrations in bean roots at different DNP concentrations were not statistically significant. However, increasing inhibitor concentrations did progressively increase the percent of adsorbed sodium translocated to the shoot. These results suggest that translocation to the shoot is not reciprocally related to accumulation in the root and that the mechanisms for accumulation in the root and translocation to the shoot are independently affected by DNP.

In the course of studying various enzyme systems of plant tissue at Riverside, California, an acid phosphatase specific for glucose-1-phosphate was discovered in cotyledons of seeds from various species. Many phosphatases with varying degrees of specificity have been described in plant, animal, and microbial tissue; however, a phosphatase limited to glucose-1-phosphate as substrate has not been reported in plant tissue. Of all seeds tested, glucose-1-phosphatase is present in largest amount in mung bean seeds. Therefore, using extracts of mung bean seeds as starting material, studies are underway to purify the enzyme, examine its properties, and determine its distribution in the plant world, and, perhaps its function in the overall physiology of the germinating seed. (SWC 7-gF7)

Results from a PL-480-supported study at the Hebrew University of Jerusalem, Israel, show that the rate of leaf area growth and the final leaf area were larger for bean plants grown continuously in a nonsaline medium, but that the rate of leaf thickness growth and final leaf thickness were larger for beans grown in the saline medium. Transfer of plants from nonsaline to saline medium resulted in retardation of growth in both leaf area and thickness, and in reduced water content of the leaves. Transfer of plants from nonsaline to saline medium resulted in a decrease in transpiration and transfer in the other direction resulted in an increase in transpiration. (A10-SWC-7)

4. Effects on plants of specific ions associated with salinity or exchangeable sodium. At Riverside, California, the second year's observations on chloride accumulation in two table grape varieties grafted to five different rootstocks and grown in sand cultures at three chloride levels fully confirmed the first year's findings. The rootstocks have maintained the same relative effectiveness in regulating chloride accumulation. In order of decreasing leaf-chloride content, the ranking of rootstocks is Cardinal, Thompson Seedless, Dog Ridge, 1613-3, and Salt Creek. In the first year, vines on Cardinal roots were, on the average, 14 times as high in leaf chloride than those on Salt Creek; this year, the ratio was 10. Relative accumulation in the leaves was directly proportional to the chloride concentration in the growing medium, which ranged from 12-1/2 to 50 meq./l., and the relative performance of the rootstocks was very consistent over this range. Leaf burn occurred in both grape varieties only on Cardinal roots, which produced leaf-chloride levels of about 1 percent on the high-chloride treatment. Cane samples collected during winter pruning of vines exhibited the same ranking of rootstocks with respect to chloride content as did the leaves. All canes were low in chloride, and the range among rootstocks was only 3-fold instead of 10- to 14-fold as for the leaves. The chloride content of the canes increased by only 56 percent with increasing chloride concentration of the medium, as compared with an increase in leaf chloride of more than 300 percent. When growth was estimated from the weight of pruned canes, no consistent effect of growth on chloride accumulation in the leaves was manifest, although different rootstocks did cause marked differences in vine vigor. These findings confirm the primary importance of the roots in regulating the transport of chloride to the leaves. Since chloride damage is a major cause of injury to grape vines on saline lands, the selection of chloride-resistant rootstocks has great significance. (SWC 7-gF8)

C. Water Composition, Ground Water, and Salt Balance.

Some ground waters in Western United States, especially those from deep aquifers, contain appreciable concentrations (5-10 p.p.m.) of F. With water shortages increasing, there is pressure to attempt to utilize high F waters for municipal purposes as well as for irrigation. There is no awareness of F toxicity to crops irrigated with high F waters but, as is well known, consumption of water containing over 1-1.5 p.p.m. of F by children causes mottled teeth. Two questions with respect to F in waters are currently of interest: (1) What is the fate of F added in irrigation water to soils, and (2) what are the possibilities of removing excess F from waters for municipal use by adsorption on soil? The adsorption of F by soils and common hydroxyl-containing minerals found in soils in the F concentration range of 2-20 p.p.m. has been studied at Riverside, California.

Gibbsite, kaolinite, halloysite, precipitated $Al(OH)_3$, and all soils studied adsorbed significant amounts of F with release of OH^- at the F concentrations, at the low range of those studied. The adsorption is concentration dependent and was described, in most cases, by the Langmuir adsorption equation. At an equilibrium F concentration of 16 p.p.m. the adsorption in mg./kg. was as follows: alkaline soils, 59-115; acid Aiken soil, 1070; gibbsite and leolinites, 190-295; dehydrated halloysite, 1400; hydrated (expanded) halloysite, 1777; and precipitated $Al(OH)_3$, 32,600. Goethite, bentonite (montmorillonite), and vermiculite adsorbed no more than traces of F. Similar adsorptions by dehydrated and expanded halloysite show that contrary to general belief, F at low concentrations does not replace crystal lattice OH. Instead, the very high adsorption by precipitated $Al(OH)_3$, together with the much higher adsorption by high $Al(OH)_3$--containing acid soil as compared to alkaline soils, suggests that F is primarily adsorbed by exchange with surface hydroxyls of $Al(OH)_3$. It is concluded that F probably never attains phytotoxic concetrations in irrigated soils owing to adsorption and that under some conditions such as the availability of soil having high permeability and high F adsorption capacity, it might be practical to remove excess F from water for municipal use by a system such as that used for ground water recharge. (SWC 7-gF10)

Salt balance studies have been conducted since 1961 on a 1,000-acre citrus-producing area near Riverside, California, that is irrigated with Colorado River water. The changes in soil salinity and cation exchange status of the soil have been compared with total input and output of salts. Trends observed to indicate that the soils will reach the chemical equilibrium status predicted by theory. Although winter rainfall has contributed significantly to removal of salts accumulated in the soil during the summer irrigation season, extra irrigation water has been needed to maintain a soil condition favorable for citrus production. (SWC 7-g1)

Seasonal fluctuations in the salt concentration of stockwater ponds have been studied for two years at Newell, South Dakota, where soils in depressions are frequently salty. Salt concentration increased as the water level decreased during the season, but the concentration of none of the 45 ponds checked ever reached a level toxic to livestock. Highest salt concentrations were found in ponds located on fine-textured soil. Salt concentration was homogeneous throughout the pond at a given sampling time. There was no indication of any significant amounts of nitrate. (SWC 7-d1)

D. Water, Soil and Crop Management Systems for Saline and Sodic Soils

At Grand Forks, North Dakota, the effect of various management systems on soil salinity was studied at two sites that differed in salinity and depth to the shallow, saline water table. Two years of data show that soil salinity in the surface foot was reduced quite uniformly for all treatments at the moderately saline site. In the second foot, salt reductions progressed with time, but were greatest under continuous fallow and straw mulch on fallow. At the highly saline site, soil salinity was decreased most under the straw mulch treatment. Yields of barley (straw + grain) at the highly saline site were 15 times greater for the straw mulch treatment than for the other treatments. (SWC 7-d1)

In studies of the effects of salt-tolerant grasses on the reclamation of saline soils under dryland conditions at Weslaco, Texas, yields of Coastal bermudagrass and rhodesgrass were 6.4 and 6.2 tons/acre on non-saline soils and 4.8 and 5.0 tons/acre on saline soils, respectively. Moderate soil salinity reduced slightly the forage yield of Atlas sorgo (1.3 to 1.0 tons/acre) and barley (2.1 to 1.7 tons/acre). Barley would be an acceptable forage crop for the fall and winter months.

At Weslaco, Texas, fallowing decreased the K^+ and Na^+ content in both saline and nonsaline soils, and decreased Ca^{++} in the saline soils. The Mg^{++} concentration increased in both soils. Rhodesgrass increased the Na^+, Ca^{++}, and Mg^{++} content of nonsaline soils and the Mg^{++} content of saline soils, whereas bermudagrass increased the Na^+ and Mg^{++} concentration of nonsaline soils. Complete reclamation of saline areas by growing grasses is not feasible in the area.

At Weslaco, Texas, sand-gravel mulch and cotton gin trash mulch have continued to be effective in reducing soil salinity under natural rainfall conditions, but salinity has fluctuated under the bare fallow and Coastal bermudagrass treatments. Bicarbonate ion concentration of the soil solution has increased in all treatments except the bermudagrass. Chloride ion concentration has decreased. (SWC 7-e1)

E. Leaching Processes

Studies of the leaching requirement have been initiated at Riverside, California, in well-drained field plots and in gravity-drained lysimeters with an effective water table at 4 feet. Harding grass is used as the test crop. In the field plots, leaching percentage affected yield at the 1-percent level of significance, and the water-salinity and leaching percent interaction was significant at the 5 percent level. With the highest rate of leaching for each of two waters, yield of Harding grass declined only a

few percent, compared to the nonsaline control, but decreasing the leaching percentage to one-half or one-quarter of the highest level increased the yield reduction to 25 percent or more. This occurred despite the fact that maximum observed salinities were still far less than the calculated maximum salinities for the treatments at the lower leaching percentages. Results indicate that the leaching requirement cannot be significantly reduced below the highest level employed without serious losses of yield.

The yields from the lysimeters at Riverside were significantly affected by salinity of the irrigation water, and there was again a significant salinity and leaching percentage interaction. Yields were reduced by 10 percent when the maximum salt concentration in the soil water of the root zone was in the 9-12 mmhos./cm. range, indicating that the highest leaching percentage employed would be necessary for adequate salinity control. (SWC 7-gF11)

Investigations during the last five years at Norfolk, Virginia, indicate that winter rainfall is usually sufficient to leach accumulated salts out of the soil profile. During the last two years, however, where high salt concentrations had been applied in the fall, some effect carried over to the spring and summer. Periodic sampling showed that there is a gradual buildup of salinity at depths of 5 and 6 feet in the Woodstown fine sandy loam at Norfolk, Virginia. Some accumulation was evident for the same treatments on the Sassafrass fine sandy loam at Painter, Virginia, but none was evident on the Rumford loamy fine sand at Currituck, North Carolina. (SWC 7-a1)

F. Spectral Reconnaissance for Diagnosis of Soil and Water Management Problems.

At Weslaco, Texas, it has been shown that predictions of vegetation's infrared reflectance on aerial photographs from spectrophotometer reflectance studies of individual leaves can be very misleading. Numerous investigators have made such predictions in the past. Models consisting of multiple layers of cotton leaves in direct contact with each other, and with layers separated by several inches, show that near-infrared light transmitted through the surface leaves of plants is reflected from lower layers, much of it being retransmitted through the top canopy to reinforce the reflected light.

At Weslaco, Texas, field and greenhouse experiments showed the effects of a number of plant and related soil factors on spectral reflectance of individual cotton leaves. The percent of incident light reflected from individual cotton leaves decreased in the visible wavelength and increased in the near-infrared wavelengths as the leaf matured, and as the nitrogen and chloride content of the leaf increased. A decrease in the total moisture content or in relative turginity of single cotton leaves increased reflectance and transmittance of the incident light. The effects of moisture were most pronounced at the wavelengths 1450 and 1930 mμ.

Spectrophotometer studies at Weslaco, Texas, have shown that reflectance and transmittance curves from leaves of agricultural crops exhibit many important anomalies in the 320 to 2500 millimicron (mμ)wavelength interval. The wavelengths between 900 and 2500 mμ have been rarely studied in the past because of heretofore lack of instrumentation for sensing in these wavelengths. (SWC 7-18(e2)

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AREA 8: WATER AND WIND EROSION CONTROL PRINCIPLES, PRACTICES, SYSTEMS AND PREDICTION METHODS

Problem: Soil erosion is a widespread hazard, limiting land capability on 738,000,000 acres in the United States. Erosion by water or wind, or both, continues to be a problem in all areas having cropping systems that require plowing, tilling, and planting. It is also a problem of increasing importance on construction sites.

Sandblasting has caused serious damage to young plants in the sandy vegetable-producing areas of the humid region. Careless application of irrigation water has resulted in serious erosion.

Erosion is the major source of stream pollution in humid and semiarid areas. Much of this pollution is from the greatly expanded residential and industrial developments and from highway construction.

Continued development of new erosion control practices and modification of existing ones are necessary to meet the needs of an ever-improving farm technology and the expanding use of multi-row farm equipment.

The wide variations possible among different soils, climates, crops, and management systems create highly complex relationships that make it imperative to determine basic principles governing the movement and loss of soil and water. Improved control measures and prediction equations developed from these principles will provide a scientific basis for application of control practices, identification of potential sediment sources, preparation of land use recommendations and selection of critical areas for retirement to permanent vegetation.

USDA AND COOPERATIVE PROGRAM

The Division conducts both basic and applied research and development in the area of water and wind erosion utilizing soil physicists, soil scientists, analytical statisticians, and agricultural engineers at various physiographic areas and field stations throughout the United States. The scientific and engineering effort in this area totals 23.1 professional man-years per year with 9.5 devoted to basic principles and mechanics of water and wind erosion; 7.6 to interrelations of climate, soil, topography, cover and management; 1.2 to equations for predicting soil and water losses; and 4.8 to practices, structures and systems for modification of soil movement by wind and water.

PROGRAM OF STATE EXPERIMENT STATIONS

A total of 15 scientific man-years is devoted to this area of research.

PROGRESS -- USDA AND COOPERATIVE PROGRAMS

A. Basic Principles and Mechanics of Water and Wind Erosion

1. Mechanics of water erosion. At Watkinsville, Georgia, studies of the critical tractive force, T_c, needed to initiate soil movement in a crop row channel were made for 9 Piedmont soils. T_c is the force in lb./ft.^{2} exerted on the soil in the channel at the time soil particles begin to move. Textural analyses of these soils showed the percentage of primary particles ranged from 33.5 to 78.4 for sand, 10.3 to 50.3 for silt, and 11.3 to 46.8 for clay. Values of T_c for these soils in the unconsolidated state, as in freshly tilled land, and without rainfall effects, ranged from 0.0053 for Appling sandy clay loam to 0.0071 for Herndon silt loam. Stepwise regression analyses made between T_c and various soil physical and chemical properties showed that T_c was highly correlated with 20-micron suspension percentage, 50-micron dispersion ratio, coarse sand content, 20-micron dispersion ratio, and pH. The single parameter of 20-micron suspension percentage explained 45 percent of the variation in T_c between the different soils. The positive correlation of T_c with dispersion ratio indicates that the force required to initiate soil movement increases with an increase in dispersion, or, conversely, T_c decreases as aggregation increases. This suggests that the aggregates act as discrete particles, but being less dense than single-grain particles, are more easily moved. (SWC 8-b2)

Laboratory studies at Lafayette, Indiana, showed that the influence of soil particle roughness on soil erodibility increases as particle size decreases. Particles with roughnesses ranging from smoothed sand to crushed glass were of nearly equal erodibility in the 500-micron sizes, but in the 100-micron sizes, the roughest particles, crushed glass cullet, were about 50 percent more erosive.

Critical limits of slope steepness, S_a, slope length, L_a, and particle size, D_a, where appreciable erosion began, were found to be interrelated. The data for angular particles showed excellent fits of the equation, $L_a^u S_a^v = K$, where u/v and the constant, K, were functions of D_a and particle roughness. For the 500-micron particles, the critical limits of slope steepness and slope length were essentially the same for all particle shapes, but they varied greatly with roughness for the 100-micron particles.

Various physical relationships that relate the size and quantity of soil transported by flowing water to the velocity of flow were combined with hydraulic formulas that relate velocity to the geometry of the flow channel for both turbulent and laminar flow. The expressions obtained in this manner were very similar to existing empirical erosion relationships. (SWC 8-c1)

In previous studies at Lafayette, Indiana, the erosion rates of sand-sized spheres increased as the particle size decreased from 460 to 58 microns. However, erosion rates of silt-sized (33-micron) spheres were similar to those found for 58-micron spheres. The increased transportability of the silt-sized particles was apparently offset by their decreased detachability due to greater cohesive properties. (SWC 8-c1)

At Lafayette, Indiana, wheat-sized plant stems were not effective in reducing soil movement by runoff until their population was high enough to appreciably decrease the average flow velocity and to prevent serious rilling. For 7-inch rows, populations greater than 3,000,000 stems per acre were required to reduce soil movement. When planted at similar populations, stems in 14-inch rows were much less erosive than stems in 7-inch rows. Stems at populations and orientations that did not appreciably decrease the flow velocity consistently caused more erosion than when no stems were present. The stems apparently affected the turbulence, boundary layer thickness, and other flow characteristics that influence soil movement. These phenomena will be investigated further. (SWC 8-c1)

Investigations at Ames, Iowa, showed that the amount of rainfall energy required for breakdown of soil aggregates to a point where runoff begins is determined by the size distribution of aggregates as well as by their stability under raindrop action. In field-plot tests, water intake was substantially higher on Marshall subsoil than on Marshall surface soil. The stability of aggregates in the 20- to 25-mm. size fraction was the same for both soils, but the subsoil contained a much higher percentage of aggregates greater than 9 mm. This suggests that water intake can be substantially increased on many soils by tillage techniques that increase the aggregate size distribution.

In laboratory studies at Ames, Iowa, primary-particle size distribution of soil in runoff after the erosion rate reached equilibrium approached that of the original soil material. The surface seal contained more silt and less clay than the original soil. Almost 90 percent of the material in the surface seal of Marshall silty clay loam was silt or silt-sized aggregates. The hypothesis that information on dry aggregate strength and clay content might serve to predict the resistance of soil aggregates to breakdown under raindrop action was not fully confirmed by a study of nine soils. (SWC 8-c2)

2. Dust transport and deposition. From headquarters at Manhattan, Kansas, 17 cooperative dust-trapping stations are now operating in the United States east of the Rocky Mountains. Four new stations were established to obtain replicated samples, evaluate effect of height of sampler above the soil surface, and study the effect of atmospheric deposition on the Florence soils typical of the Flint Hills rangelands of Kansas. Average amounts of dust influx for the network continue to be large enough to influence soil genesis and renewal. Amounts this year ranged from 257 to 2,350 pounds per acre. Major influx occurs in the spring and early summer. Preliminary

analyses of climatological data in relation to dust catch indicate that wind velocity and direction at a particular site have less influence on magnitude of catch than originally believed. The percent of clay, ranging from 10 to 80 percent, does not appear to follow any uniform trend, except to be slightly less during major influx. The sand and silt fractions consist of several minerals, but quartz, calcite, and iron-stained aggregates usually predominate. Other minerals include opal phytoliths, glass, zircon, tourmaline, clay aggregates, and microcline. (SWC 8-e1)

3. Freeze-thaw effects on runoff and erosion. Water erosion in the Pacific Northwest is unique in that runoff generally occurs during periods when the soil is frozen near the surface, but is thawed and saturated at the surface. Erosion control becomes a problem of either maintaining the infiltration rate at a sufficiently high level even though the soil is frozen, increasing the time the water is retained on the land, stabilizing the surface soil to increase its resistance to detachment, or modifying the rate of water accumulation by decreasing the rate of snowmelt. Ironically, the runoff and erosion problems often occur on steeply sloping, nonirrigated farmland where yields are later limited by lack of available water in the soil profile. For example, the total precipitation from October 28, 1964, to May 12, 1965, was 9.14 inches near St. Anthony, Idaho. Runoff during this period amounted to 6.8 inches or about 75 percent of the precipitation, even though the water-holding capacity of the effective rooting depth of these soils could have retained most of this water if infiltration had been possible. New studies are being initiated at Pullman, Washington, to obtain basic information on the factors that influence the thermal properties of soils and the thermal regime under various common and extreme tillage practices. These studies will assess the significance of the thermal properties on frequency and depth of soil freezing and thawing, and assess the effects of thermal gradients on the distribution of water in the soil profile during the winter season. (SWC 8-f2)

4. Soil erodibility. Field measurements and associated laboratory determinations on 68 Corn Belt soils have provided information for calculating the erodibility of specific soils throughout the broad range between deep sands and heavy clays. On soils with sand fractions ranging from 4 to 64 percent and silt fractions from 24 to 75 percent, the effect of texture on erodibility depended very much on its interrelation with other variables. The two variables most closely correlated with runoff amount were suspension percentage and organic-matter content; the two most closely correlated with soil concentration in the runoff were organic-matter content and percent slope. Eight soil properties or site conditions and 15 interaction terms accounted for 78 percent of the variance in runoff and 82 percent of the variance in soil concentration in the runoff. The soil properties and site conditions were: percent sand, percent silt, clay ratio, organic-matter content, aggregation index, suspension percentage, percent slope, and antecedent soil moisture. (SWC 8-c2)

Studies at Watkinsville, Georgia, indicate that a measure of soil erodibility can be predicted when certain soil and site properties are known. The prediction equation takes the form $Y = A_o + A_1X_1 + \text{----} A_nX_n$, where Y = soil loss in t/acres/EI; A_o, A_1----A_n are constants; and X_1----X_n are independent variables representing soil and site properties. Regression analyses showed that measured soil loss resulting from a 100 EI storm on soils with kaolinitic clay was explained by 8 parameters. These were land slope, antecedent soil moisture in the surface 3 inches ÷ field capacity, percent clay/(percent silt + percent sand), percent fine sand, log n percent very fine sand, /(percent silt + percent very fine sand)/ percent clay/ x slope, log n percent particles >2.0 mm., and depth of A horizon. The values determined for the constants are: $A_o = 0.007$, $A_1 = 0.004$, $A_2 = 0.052$, $A_3 = -0.117$, $A_4 = -0.004$, $A_5 = 0.054$, $A_6 = -0.002$, $A_7 = -0.014$, and $A_8 = -0.001$. Since these values were obtained with a rainfall simulator, further adjustments may be required. (SWC 8-b1)

Soil erodibility values (K values for the erosion equation) for several additional soils were determined as follows:

Black Belt of Alabama - Rain simulator

Sumter clay	0.35 (T/Acre/EI)
West Point clay	0.36
Oktibbeha clay	0.23
Oktibbeha-Vaiden clay	0.12
Vaiden clay	0.06

Tifton, Georgia - 1960-65 average - Natural rain plots

Tifton sandy loam	0.05

Holly Springs, Mississippi - 1962-65 average - Natural rain plots

Loring silt loam	0.66
Lexington silty clay loam	0.54

(SWC 8-b1)

5. Erosion tolerance and renewal. At Manhattan, Kansas, quantitative information on length of time required for renewal of Austin clay was obtained by analyzing sorghum yield, porosity profiles, and surface tilth data from two field plots desurfaced to a depth of 15 inches in 1931 and 1961 at Temple, Texas. Results showed that complete renewal had not been attained in 34 years. Grain yields from 1963-1965 for the plot desurfaced

in 1961 were similar to that for the plot desurfaced in 1931, but were 500 pounds per acre less than for normal soil. Desurfaced plots had higher bulk density and lower porosity in the top 18 inches of soil, lighter color, less favorable surface tilth, and approximately 1.0 percent less organic matter. (SWC 8-10(e2)Rev.)

B. Interrelations of Climate, Soil, Topography, Cover and Management

1. Water runoff and erosion. With a 1963-65 3-year average rainfall of 48.5 inches at Holly Springs, Mississippi, the average annual runoff was 24.8, 12.3, 11.0, 11.0, and 4.9 inches from fallow soil, common bermudagrass sod, corn after bermudagrass, corn continuously in rows upslope and downslope, and in rows with closed-end contours, respectively. Average annual soil losses from these same conditions were 92.6, 1.2, 2.8, 1.7, and 0.6 tons per acre. Runoff losses from 48.9 inches of rainfall on fescue-grass on a 7-percent slope at Watkinsville were 3.1, 1.3, and 3.0 inches from first-year sod, second-year sod, and corn after sod, respectively. Soil losses from these crops were 0.7, 0.1, and 1.5 tons per acre per year, indicating that row crops can be grown without fear of serious erosion on fairly steep slopes when rotated with a good sod crop. (SWC 8-b1)

At Tifton, Georgia, runoff and soil losses on Tifton sandy loam with 3-percent slope for 5 years averaged 12.6 inches of runoff and 5.4 tons per acre of erosion from cultivated fallow soil, while 10-year average losses were 1.8, 2.6, and 0.9 inches of runoff, and 1.3, 1.2, and 0.3 tons per acre of erosion from Spanish peanuts after rye, corn after rye, and oats, respectively, in a 3-year rotation with contour tillage. In a 4-year rotation of crimson clover and bahiagrass, second-year grass, corn, and peanuts the annual losses were 3.7, 0.4, 0.9, and 2.1 inches runoff and 0.6, 0.3, 0.6, and 1.1 tons per acre soil loss, respectively, for these crops. These data indicate that both surface runoff and erosion can be reduced to a very low annual amount with judicious treatment of cropland in the Southern Coastal Plain land resource area. (SWC 8-b1)

Annual runoff from corn grown continuously on controlled row grade plots of different slopes at Holly Springs, Mississippi, for the four-year period, 1962-65, was 13.4, 14.4, and 19.2 inches for 2.5-, 4.25-, and 10.0-percent slopes, respectively, indicating a linear relationship between slope and runoff. Soil losses under these same conditions were 3.7, 4.0, and 9.1 tons per acre, indicating a curvilinear relationship between erosion and land slope. (SWC 8-b1)

Adequate soil fertility substantially increased the efficiency with which available water was utilized by corn plants during three successive dry years at Columbia, Missouri. Full fertility reduced runoff and evaporation losses by providing effective canopy cover more quickly. It also promoted deeper root development and thereby enabled the corn plants to draw 0.7 inch more water per year from the 24- to 36-inch soil depth. Corn yields on the full-fertility treatment averaged 100 bushels per acre,

in contrast to 36 bushels where only starter fertilizer was applied. During the relatively wet 1965 growing season, removal of water from the soil by the thriving corn plants increased infiltration and reduced erosion. These findings are applicable on about 10 million acres of Midwest claypan soils. (SWC 8-c2)

Surface mulches of straw applied at rates of ¼, ½ and 1 ton per acre to a slowly permeable, forest soil at Lafayette, Indiana, reduced the flow velocities of runoff on gently sloping fallow plots to 14, 12, and 7 feet per minute, respectively. The flow velocity on plots with no mulch averaged 26 feet per minute. The decrease in velocity of surface runoff effected by the ¼ ton rate of mulch reduced soil loss about 60 percent. These results show that surface mulch is effective in reducing soil erosion even on slowly permeable soils, where its effect on infiltration may be small. (SWC 8-c2)

In four years of measurements on Poinsett soils of eastern South Dakota, two-thirds of the runoff and four-fifths of the soil loss from conventional corn occurred during the first two months after corn planting. Both soil and water loss in this critical period were greatly reduced by modification of tillage methods. Wheeltrack planting in straight rows reduced May and June soil loss by 50 percent and water loss by 36 percent, and wheeltrack planting on the contour reduced both by 90 percent. Mulch tillage reduced soil loss 47 percent and increased corn yields 8.5 bushels per acre. (SWC 8-c2)

In plot studies on Barnes and Grundy silty clay loams in Minnesota and Iowa, the canopy cover of soybeans, during the period from two months after seeding until harvest, was significantly more effective in reducing runoff and erosion than that of corn. (SWC 8-c2)

Soil moisture content at the time of primary tillage significantly influenced the amount of soil lost in the runoff from subsequent rainfall on silt loam to silty clay loam prairie soils in Indiana. Losses were nearly twice as great as plots plowed when wet as on those plowed when moisture in the upper 4 inches was several percent below field capacity.

The first year of a study of the influence of oriented microtopography on erosion of Barnes soil in western Minnesota showed a progressive increase in soil loss per unit area as ridge angle was increased from 7.5° to 30° and as ridge slope length was increased from 4 inches to 12 inches. Increases in soil loss appeared to be linearly related to increases in wetted perimeter of the furrow. (SWC 8-c2)

Tillage practices such as stubble mulch tillage and subsoiling can significantly reduce the amount of soil erosion that occurs in the Pacific Northwest by runoff during the winter precipitation period. Stubble mulch tillage in the Upper Snake River dryland area has not been a common practice because cheatgrass control appeared to be more difficult than with moldboard plowing. Studies at St. Anthony, Idaho, have shown that early sweep fallow

tillage with rod weeding just prior to planting and a slightly delayed seeding date gave complete control of cheatgrass and resulted in average wheat yields of 45 bushels per acre. In contrast, delayed sweep fallow tillage resulted in as many as 29 cheatgrass plants per square foot and wheat yields as low as 5 bushels per acre. These data illustrate that, properly implemented, stubble mulch tillage can be utilized for erosion control in this area during the fallow period without an economic loss. (SWC 8-f1)

2. Wind erosion. At Manhattan, Kansas, a laboratory study has shown that a soil packing component to a tillage implement for increasing soil cloddiness by intermittent cloddiness to control wind erosion should meet the following design criteria: (1) Deliver a packing pressure equal to or greater than 22 pounds per square inch, (2) have a size or area equal to or greater than 17 square inches, (3) provide a spacing between component centers equal to or less than 8 inches, (4) have from 350 to 700 impacts per minute, and (5) a stroke equal to or greater than 6 inches. (SWC 8-e1)

Minimum tillage of summer-fallow land for wheat at Colby, Kansas, conserved more residue, but excessive weed growth with consequent greater use of soil water resulted in lower wheat yields than did regular four- or five-operation-per-summer stubble mulch tillage. But a tillage system that skipped some operations, included a tillage-herbicide treatment, and used a rotary mower and tandem disk to destroy large weeds just before wheat planting, conserved from 20 to 60 percent of the original 2,800-pound-per-acre average residue for overwinter wind erosion protection. The usual four- to five-operation stubble mulch tillage system conserved only 4 to 15 percent of the original residue. (SWC 8-e1)

At Alliance, Nebraska, draft measurements of several stubble mulch tillage machines, made in connection with evaluations of the tillage machines' role in conserving residue for wind erosion control, showed that the new flexible-frame subsurface-sweep tillers have slightly lower power requirements than the rigid-frame tiller. Relative data obtained from tillage of a weed-free oat stubble to a 5-inch depth on a Keith fine sandy loam soil showed 5.2-, 3.0-, and 2.7-hp.-per-foot power requirements for the one-way disk, rigid-frame sweep tillage, and the flexible-frame sweep tiller, respectively. However, draft was also affected by weed growth, and other tests on wheat stubble with a substantial number of large-rooted weeds showed 3.7-, 4.3-, and 4.1-hp.-per-foot requirements for the one-way disk, rigid-frame sweep tiller, and flexible-frame sweep tiller, respectively. Power requirements for mulch treader and straight rodweeders, commonly used in the final cultivation and seedbed preparation operation, were about 1/2 and 1/3, respectively, of the requirements for flexible-frame subsurface sweeps. (SWC 8-e1)

At Sidney, Montana, in a 20-month safflower-fallow rotation, a cover crop (oats) seeded in late August of the summer fallow period provided

excellent wind erosion control during the second winter of fallow. A comparison of the relative wind erodibility of the cover crop-fallow system and the conventional sweep fallow method showed the erodibility of 4.02 and 1.75 tons per acre in 1962 and 1963, respectively, for the conventional fallow system as compared with only 0.07 and 0.05 ton per acre for the cover crop-fallow system for the same respective years. (SWC 8-8(d1) Rev.)

3. Rain simulators vs. natural rain plots. Soil losses on Cecil sandy loam at Watkinsville, Georgia, were 0.0954 and 0.0808 ton per acre per EI, respectively, from natural rainstorms and storms applied with a rainfall simulator on the same plots. These data indicate a ratio of 1.18:1 for losses from natural rain to those from the simulator. This is close to the computed ratio of 1.3:1 for energy relationships between natural and simulator rain of similar intensity and amount. (SWC 8-b1)

C. Predicting Soil and Water Losses

1. Water runoff and erosion. Analyses of runoff data assembled at Lafayette, Indiana, in conjunction with development of a runoff prediction equation indicated that intake of water by cropland soil was more a characteristic of surface conditions and long-time management than of soil type and topography. Over a texture range from silty clay to sandy loam, the effect of particle-size distribution was relatively small. However, runoff was substantially decreased by a high residual organic-matter level, accumulation of crop-residue material in the soil, residue mulches, tillage practices that preserved soil structure and left interrow areas cloddy, and sod-based rotations. Decomposed residue material, distributed through the plow layer by normal tillage operations, substantially increased final infiltration rates and was highly effective in reducing runoff from rains of relatively long duration and high intensity. Annual incorporation of the residue from 90- to 115-bushel continuous corn yields reduced runoff during the spring-fallow and corn-seedling periods by an average of 40 percent.

However, the beneficial effects on water intake of annual incorporation of corn residue were not as great as those of meadow sod turned under before corn. Even at high-level management for both systems, corn following sod averaged one-third less runoff than continuous corn.

Data from eight States showed that, contrary to past assumptions, runoff from cropped land usually does increase as land slope steepens. Analyses of the individual-storm data indicated that this is primarily a result of the influence of slope on surface detention of rain, and that the magnitude of the effect under given conditions is predictable. For intertilled crops, the relationship was curvilinear; for small-grain cover, linear; and for dense sod, insignificant. The relation was also insignificant on highly smoothed soil surfaces, which provided essentially no surface detention and sealed quickly under raindrop impact.

Analysis of the slope-length data indicated that practices which increase infiltration of water into the soil are relatively more effective in reducing soil loss from a short slope than from a long one. The effect, however, of slope length on runoff is seldom of sufficient magnitude to be of practical value in estimation of runoff amounts. (SWC 8-c3)

Results of a 3-year slope-shape study at Morris, Minnesota, confirmed the hypothesis that, for soil-loss prediction purposes, a slope length ends at the point where gradient decreases significantly. Soil losses measured at the lower ends of concave plots were substantially lower than those from uniform or convex plots of the same average gradient. Considerable deposition toward the lower end of the plot was apparent. Convex slopes lost more soil and water from 2.5-inch rains than did uniform slopes, but these differences were not apparent when similar storms were applied to saturated soils. (SWC 8-c2)

2. Wind erosion. At Manhattan, Kansas, the mathematical method reported last year for computing magnitude of wind erosion forces, prevailing wind erosion direction, and preponderance of wind erosion forces in the prevailing wind erosion direction was applied to monthly wind data at 200 locations in the conterminous United States. Results showed that consideration of the preponderance of wind erosion forces in the prevailing wind erosion direction--given by the ratio, R, of wind erosion forces parallel to these perpendicular of the prevailing wind erosion direction--and the angle of deviation, A, of a given field to right angles of prevailing wind erosion direction are extremely important factors in evaluating the field length, L, used in the wind erosion equation and in orienting barriers and stripcrops to derive maximum protection from wind erosion. Many locations in the United States have small R values, with no pronounced prevailing direction, and barrier or stripcrop orientation would have very little effect on protective influence. Where locations have large R values and very pronounced prevailing directions, very careful consideration needs to be given to angle of deviation of field strips and barriers to prevailing wind erosion direction to avoid gross errors in erosion control design and evaluations of distance of wind travel across fields. (SWC 8-e1)

D. Practices, Structures and Systems for Modification of Soil Movement by Wind and Water

1. Control of erosion by wind. Continuing field tests to evaluate plant materials for potential as single-row wind barriers at St. John, Colby, and Garden City, Kansas, show that lombardy poplar, Russian mulberry, pampas and bamboograss, common lilac, bush honeysuckle, tamarisk, American plum, caragana, kenaf, and the hybrid forage sorghum "Cropguard" have good potential for establishing single-row barriers at Colby and St. John. Average height of 3-year-old lombardy poplar at St. John is 12 feet, and 2-year-old poplar at Colby has reached a height of 8.5 feet. Mulberry at Colby after 2 years averages 4.5 feet in height and 3-year mulberry at St. John has reached an average height of 8 feet. The grasses range in

height from 7 feet for bamboo to 9.5 feet for pampas. Three-year-old shrubs range in height from 2.8 feet for lilac to 6.3 feet for tamarisk. The hybrid sorghum "Cropguard" reached a height of 6 feet at St. John and has real promise as an effective barrier. The northern shrub, caragana, has done exceptionally well at Colby, reaching a height of 4.5 feet in two years. (SWC 8-e1)

2. Damage to young plants by windblown soil. At Manhattan, Kansas, studies to evaluate windblown sand abrasive injuries to vegetables showed that relatively low rates of sand movement and short periods of exposure to wind severely damaged green bean seedlings and caused substantial yield reduction. Wind alone at speeds up to 40 miles per hour caused only slight damage. Introduction of as little as 0.2 ton sand per rod width per hour into the windstream greatly increased plant injury. Plant damage increased linearly and bean yields decreased almost linearly with increase in windspeed and duration of exposure. Although plants abraded at a windspeed of 20 miles per hour were injured, they recovered sufficiently to yield well. The yield of plants abraded at 30 and 40 miles per hour decreased with increased sand flux.

At Big Spring, Texas, the first year's data from portable wind tunnel studies to evaluate the effect of wind erosion on cotton showed that increasing rates of sand blasting caused later dates of first bloom, killed more plants, and decreased growth rates. However, plants that were not killed exhibited remarkable recovery powers under the favorable soil moisture conditions and late frost dates at Big Spring this year and lint yields were not reduced. (SWC 8-e1)

3. Contour and terrace systems. Data for four years (1962-65) at Holly Springs, Mississippi, show that runoff and soil losses on a loess silt loam soil are 2 and 3.6 times, respectively, greater from corn with rows run with the slope than from corn with closed-end rows on the contour. Soil losses between terraces in 1965 from corn in contoured rows were 2.7, 2.5, and 3.8 tons per acre where the slopes were 2.5, 4.25, and 10.0 percent, respectively. Soil losses totaled 1.9 tons per acre from corn in a 1.45-acre field with parallel terraces and contour rows, and with slopes ranging from 4 to 10 percent. The lower losses from the terraced field indicate that at least half the soil that is moved from the interterrace area is deposited in the terrace channels or grassed waterway in the field. (SWC 8-b1)

At Cherokee, Oklahoma, where movement of soil into terrace channels and the effect of the terrace channel on sediment production is studied with variable slope length interterrace plots and paired concrete and natural channel terraces, data from 11 runoff-producing storms during the period August 13, 1964, to September 20, 1965, showed that the terrace channel serves as a sediment trap. Average loss from the 200-foot-long, concrete-lined channels was 1.1 tons per acre and from the natural earthen channels, 1.0 tons per acre. Results from the variable slope length interterrace plots showed that as slope length increased, soil loss decreased, at least

for lengths up to 100 feet. Average loss for the 11 storms was 2.3, 2.0, 1.4, and 1.4 tons per acre for the plots with lengths 33.3, 66.7, 100, and 166.7 feet, respectively. (SWC 8-10(e2) Rev.)

At Temple, Texas, an area of graded furrows with row lengths of 340, 520, and 930 feet effectively controlled runoff and erosion and produced an above-average oats crop. Harvesting was no more difficult than on adjacent flatlands. Total runoff for the year from the triplicated areas averaged 0.64, 0.52, and 1.51 inches from the 340-, 520-, and 930-foot rows, respectively. Incomplete erosion data was obtained because of equipment malfunctions; however, during storms in January and May when complete data was obtained, total soil losses were well below accepted tolerance levels, averaging 0.06, 0.05, and 0.11 ton per acre from the 340-, 520-, and 930-foot row lengths, respectively. Oat yields were largest from the 930-foot rows, averaging 60 bushels per acre, and lowest from the 340-foot rows, averaging 48 bushels per acre. (SWC 8-10(e2) Rev.)

At Madison, South Dakota, study of the surface water storage capabilities of 4 corn tillage practices showed that with contour-tilled land, maximum potential surface water storage capacities increased from 1.2 inches for conventional tillage, to 2.6 inches for listing, to 3.4 inches for 8-row bedding, and to 4.0 inches for 4-row bedding. Major yield increases accompanied the greater water storage capacities. (SWC 8-c4)

Crop yields in 1965 on land terraced in the early 1950's at McCredie, Missouri, were not seriously reduced by terrace cuts of up to 2½ feet made during terrace construction. On fields where the first cutting of alfalfa yielded 2.0 tons per acre on undisturbed areas, the yield averaged 1.8 tons on areas of normal cuts (0.8 foot) and 1.5 tons on areas of deep cuts (2.5 feet). Corn yields decreased from 94 bushels per acre on undisturbed areas to 60 bushels where cuts were greater than 2 feet, but there was strong evidence that the reduction was primarily due to stand differences rather than to a limited production capability. Since areas of deep cuts are relatively small and since reduced yields in terrace channels may be partially compensated by increased yields on terrace ridges, the minor effect of deep cuts on the overall yield is generally offset by the increased efficiency of farming better aligned terrace systems. (SWC 8-c4)

4. Erosion control for construction sites. Various organic mulches and methods of anchoring the mulches to protect freshly tilled soil against water erosion were evaluated at Lincoln, Nebraska, on a Sharpsburg silty clay loam with 6-percent slope. A rainfall simulator provided intensities of 2.5 and 5.0 inches per hour on the 12- by 35-foot plots. Additional surface flows were applied to the upslope end of the plots to simulate more natural field slope lengths and to provide greater erosive conditions for final tests of mulch effectiveness. Asphalt emulsion applied at 1200 gallons per acre, prairie hay at 0.5 ton per acre anchored with asphalt emulsion, prairie hay or wheat straw at 1 ton per acre anchored by disk packing, and wood chips at 6 tons per acre all gave comparable and satisfactory erosion protection. Water intake was highest with the asphalt emulsion.

Separate studies showed that tall fescue seedlings germinated and established the best stands with the 9-ton wood chip mulch. Prairie hay mulches applied at 1- and 2-ton-per-acre rates and at a 0.5-ton-per-acre rate anchored with asphalt emulsion (150 gallons per acre) also produced good stands of grass. Single applications of asphalt emulsion, resinous binders and lower rates of prairie hay and sawdust were unsatisfactory.

Simulated storms applied to roadside bank cuts on 3:1 slopes near Lincoln, Nebraska, showed that best protection against erosion was obtained using mulches of coarse jute netting or wood-excelsior sandwiches between layers of strong netting and prairie hay (1 ton per acre), or fiber glass anchored with asphalt emulsion (150 gallons per acre). Mulches of an emulsifiable latex or tightly twisted kraft paper netting were least effective. Anchoring materials with asphalt emulsion increased adherence to the soil surface and detention of runoff water by eliminating undercutting, a serious problem on some netting materials without asphalt anchorage. (SWC 8-8(d1) Rev.)

5. Inundation tolerance of grasses. Continued tests at Chickasha, Oklahoma, to obtain information useful in designing vegetative programs for floodwater detention reservoirs for optimum forage production and minimum soil erosion have indicated that Knotgrass, Reed canarygrass, Prairie cordgrass, smooth seed paspalum, Florida paspalum, beaked panicum, Kanlow switchgrass, rice cutgrass, and the forb creek willow have sufficient inundation tolerance to be established in areas that are flooded intermittently. Kentucky fescue, Virginia wildrye, western wheatgrass, smooth brome, knotroot bristlegrass, indiangrass, and big bluestem have less tolerance but are suitable for use in upper zones of the detention pools where duration of inundation is short. The flooding tolerance of all the grasses decreased as depth and duration of flooding increased and as season of year progressed from early to late spring. Inundations during mid and late spring caused severe damage, often resulting in complete destruction of several species. (SWC 8-10(e2) Rev.)

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AREA 9: MOISTURE CONSERVATION FOR THE EFFICIENT AND EFFECTIVE USE OF PRECIPITATION ON CROPS AND RANGELANDS

Problem: One of agriculture's major plagues in the United States is recurring drought. In 1964 and 1965, the Northeastern States suffered from extensive drought. In 1965, wheat yields in the Northwest and the Great Plains were reduced by prolonged drought. Tree ring studies conducted in Nebraska show that in 269 of the last 748 years, there was sufficient drought to adversely influence crop production. Weather records at several locations in the Plains show that precipitation is below average 50 percent of the time.

During most drought years, 1 or 2 inches of water will make the difference between a crop and a failure. If some means of reducing the large loss of water by evaporation or of reducing the water used in transpiration were available, the precipitation received would be more than adequate to support good plant growth and still provide sufficient water for other uses.

The research is directed towards the development of methods for increasing the infiltration of water into the soil profile and decreasing the evaporation of soil water by physical and chemical means.

USDA AND COOPERATIVE PROGRAM

The Division conducts both basic and applied research and development in the area of moisture conservation, utilizing soil physicists, soil chemists, soil microbiologists, and agricultural engineers. At all locations, the work is done cooperatively with the respective State experiment stations.

The Federal scientific effort devoted to research in these areas totals 19 man-years. Of this total, 11 are devoted to factors influencing moisture storage; 5 to factors affecting the loss of water by evaporation; and 3 to factors influencing the use of moisture by crops.

PROGRAM OF STATE EXPERIMENT STATIONS

A total of 29 scientific man-years is devoted to this area of research.

PROGRESS -- USDA AND COOPERATIVE PROGRAMS

A. Factors Influencing Moisture Storage

1. Tillage. Results of a study at Bushland, Texas, showed that excessive tillage (approximately every 2 weeks) between harvesting and planting of the next wheat crop resulted in a decrease of about 1 inch of available

water in the soil profile at seeding time as compared with normal tillage (3 to 5 days after weed emergence). Delaying tillage until 17 or 24 days after weed emergence reduced available soil moisture storage at wheat seeding time 1.5 and 2.4 inches, respectively, compared with normal tillage. In most years, delayed tillage has not appreciably affected yields, however. (SWC 9-e1)

Dryland wheat field studies were continued near Newdale, Idaho, to compare tillage after harvest with spring tillage. Over a 6-year period, the amount of water stored on treatments chiseled or rotary subsoiled after harvest averaged ½ inch more than on treatments where the stubble was left standing through the winter without tillage. (SWC 9-f1)

Research results from past experiments at Morris, Minnesota, conclusively show that water is the factor limiting corn production in the western Corn Belt. In experiments concerned with increasing soil water storage through tillage, water intake into a Barnes soil before initial runoff was 3 to 4 times greater on plots with a rough surface. These and other data collected at Morris show that greater infiltration on tilled land results from prolonging the time to initial runoff. It is not known if this increased moisture was reflected in the yield of corn. Future studies will evaluate the influence of increased water storage by various tillage techniques on corn yields. (SWC 9-c1)

2. Fallow methods. Previous experiments conducted at Bushland, Texas, and reported in 1963, showed that wheat yields on delayed fallow were the same as those on conventional fallow. Studies made this year confirmed the hypothesis that the soil moisture at planting time was the same under both fallow systems. Weeds growing on delayed fallow in the fall after wheat harvest did extract all of the available moisture to a depth of 6 feet by the time frost killed the vegetation. Delayed-fallow land, however, had an exceptional ability to collect moisture during the winter months and during some periods of heavy rains during the second summer in the fallow period. It is speculated that the primary reason for equal or better yields under delayed fallow as compared with clean fallow is that the available moisture in the upper 3 feet of soil is usually greater under delayed fallow, even though the total profile moisture may be equal under both systems. These data are of great value to the Great Plains' wheat farmers in indicating that the costs of producing wheat can be reduced by eliminating several tillage operations during the fallow period. (SWC 9-e1)

The increased cost for tillage operations has caused renewed interest in chemical fallow. Studies initiated at Pendleton and Moro, Oregon, to compare chemical fallow with the conventional, mechanical, and a combination of chemical and mechanical methods of summer fallowing are continuing to show that weeds can be controlled by chemical treatments without adversely affecting moisture storage, nitrification, and wheat yield. Future studies will be directed to evaluating the persistence of the herbicides used to determine what influence soil temperatures, water and other factors might have. (SWC 9-f1)

Data from experiments at Akron, Colorado; North Platte, Nebraska; and Sidney, Montana, designed to evaluate the influence of various amounts of straw mulches on soil properties continue to show that mulches significantly increase soil-water storage on fallow. Soil water gained under straw mulches, especially at the higher rates, was stored deep in the profile. More than 2 inches of additional water were stored at Akron, Colorado, and Sidney, Montana, under 3,000 pounds of stubble as compared with no mulch. (SWC 9-d1)

At North Platte, Nebraska, snow trapped in the standing wheat stubble during the winter months resulted in an average of over 2 inches more available water as compared with that stored under plots with the residue incorporated in the soil in the fall. However, at all locations, grain yields were reduced by the residue treatments, especially at the high rates. The yield decrease resulted from fewer heads being produced per square foot. The application of nitrogen fertilizer raised the nitrogen content of the plant material, but did not increase grain yields. The above data indicate that we still do not understand the factors responsible for decreased grain yields on mulched land. Emphasis in future studies will be placed on determining these factors. (SWC 9-d1)

3. Land forming. Studies to determine the influence of leveled benches on the utilization of rainfall in dryland areas continued during the year at several locations in the Great Plains. In 1965, one of the wettest years on record at Akron, Colorado, an average of 15 additional inches of water was delivered to the level pan system. In spite of the excess water, low temperatures and an early frost, yields of grain sorghum on the pans were 1.5 times higher; forage sorghum, 2.1 times higher; alfalfa, 10.1 times higher; and corn, 1.2 times higher than on the unleveled contributing areas. Yields of alfalfa grown on level benches were 2.5 times greater than the yields on the contributing area at Mandan, North Dakota. (SWC 9-d1)

Two to five inches of additional water were stored under conservation benches constructed on Chama silt loam near Sidney, Montana. Conservation benches in bare fallow with contributing areas in standing stubble have consistently gained an average of 2 inches more water than conservation benches in standing stubble with a bare fallow contributing area. These data, along with Mandan data, suggest that snow accumulation on the contributing area determine to a large degree the efficiency of these systems in the Northern Great Plains. (SWC 9-d1)

In a continuing study at Akron, Colorado, to determine the ratio of size of contributing area to the bench, results in 1965, a wet year, showed that grain and forage yields decreased as the ratio of contributing area to bench decreased. Yields were lower on the leveled area than on the unleveled area because of excessive water in the benches, especially at seeding time. Artificial compaction of the contributing area increased runoff by 5 percent. These data and data collected at Mandan, North Dakota, over a 7-year period, suggest that there is no yield benefit from using a ratio of contributing area to bench greater than 1.0. (SWC 9-d1)

The search for chemicals that might be economically feasible to use as water-repellent soil amendments to increase the amount of water collected from contributing areas continues. Studies at Fort Collins, Colorado, indicate that ordinary salt (NaCl) can be a useful amendment. Runoff was increased by 200 percent with the addition of 800 pounds of salt per acre. Less than 5 percent of the salt appeared in the runoff water. These data are of particular importance to areas with limited water supplies that are interested in a low-cost material that will improve the water yield of certain soils. (SWC 9-d1)

4. Snow management. The experiment at Mandan, North Dakota, designed to determine the effect of stubble height on soil moisture accumulating from snow, continued during the year. Snowmelt runoff was greater from stubble 20 inches high than from short stubble or bare soil. On a uniform snowpack, the melt started sooner and lasted longer on plots with 20-inch stubble than on plots with 10-inch stubble or bare ground. The increased runoff on the 20-inch stubble plots was brought about by frost remaining longer in the soil. These data suggest that management practices for farmers can be developed that will provide for maximum conservation of the winter moisture that comes as snow. (SWC 9-d1)

At Akron, Colorado, field studies designed to determine the shape, volume, and density of snow drifts produced leeward of variable wood-air density snow fences show that the most efficient fence is 48 inches high and is made up of 31 percent wood. Results of these studies are of particular interest to action agencies concerned with the design of tree and grass barriers for managing snow. (SWC 9-d1)

B. Factors Affecting the Loss of Water by Evaporation

1. Type of drying. The influence of wind and radiation on loss of water by evaporation from a McGrew loamy sand was investigated at Fort Collins, Colorado. During radiation drying, the soil temperature decreased with depth but was higher at the soil surface than the air temperature; however, with wind drying, the soil temperature was lower than air temperature at all depths. The water content profiles showed a lower water content near the soil surface for radiation drying than for wind drying. The soil-water diffusivity was the same for both drying conditions. Thus, it appears that the main difference between the two drying conditions is to cause different boundry conditions at the soil surface. While the above data do not give a complete understanding, they are of great value in defining the areas of needed emphasis in future research. (SWC 9-d1)

2. Mulches. Previous studies conducted at Mandan, North Dakota, reported in 1962 and 1963, showed that plastic-covered ridges between row crops gave significant yield increases. Studies made this year, a season with 8 inches above-normal rainfall, showed the ridge coverings gave no benefits. These data suggest that yield benefits from ridge coverings can only be expected during years of below or average rainfall. (SWC 9-d1)

A "solar still" (plastic canopy) was used to measure the moisture loss by evaporation from various amounts of straw mulches at Akron, Colorado. Results showed that 1,000, 2,000, and 3,000 pounds of straw mulch per acre reduced evaporation losses 16, 33, and 49 percent compared with no straw during a 20-day test. The measured reduction in evaporation losses with increasing rates of mulch was attributed to a reduction of soil temperature and the individual straw particles acting as condensation focal points of vapor flow. These data are of particular interest in those areas where evaporation losses are large. (SWC 9-d1)

3. Frozen soils. The question of how much moisture is lost from a frozen soil remains unanswered. During the year, active evaporation loss studies from frozen soils with various covers continued at Mandan, North Dakota. Results show that losses for a bare soil can be as high as 7.4 inches for a 100-day winter season as compared with no loss from plots covered with plastic. Losses vary greatly with season, being very high during mild winters and low during cold winters. The loss from bare soil during mild winters is equal to that from ice, but during cold winters, the loss from ice is about twice that from bare soil. (SWC 9-d1)

4. Moisture loss from fallow without cover. It is generally believed that moisture loss by evaporation below the surface horizons is nil. Detailed analyses of 3 years of data acquired in a temperature-moisture relations study at Weslaco, Texas, do not substantiate the belief. Under a range of controlled soil moisture regimes, the average depletion under cotton was 33 inches as compared with 14 inches under fallow. Downward water movement was negligible in this study. Of particular interest, however, was that the proportion of the total depleted from each soil depth was nearly the same for cotton-cropped and fallow treatments. The 3-year average depletion by 1-foot depth to 5-feet depths in percent of total was 47.5, 27.1, 15.3, 7.0, and 3.0 under cotton, and 45.3, 24.5, 17.1, 9.0, and 4.0 under fallow. These data show that 30 percent of the total depletion under fallow occurred below 2 feet in the profile. (SWC 9-e1)

5. The influence of chemicals on evaporation losses. In a PL-480 study in Israel, concerned with evaluating the effects of several chemicals on the loss of water by evaporation, wax emulsion reduced the evaporation during the first 25 days in a loessial column but later lost its effect. In the same study, detergent solution and hexadecanal were not effective. Field soil moisture measurements made with a neutron probe failed to provide exact data on moisture gradients and fluxes. A two-probe gamma-ray field scanner will be used to evaluate moisture in future field studies. (A10-SWC-32)

6. Measuring moisture loss. The calibration of neutron emission equipment used universally for measuring soil moisture loss, has not been completely worked out. Field calibrations of a neutron moisture probe used in a study to evaluate evaporation losses from various soils at Riverside, California, have shown some significant variations among soil types. While the linear correlation between count rate and soil moisture content for each soil has

remained high, the slope of the regression line relating moisture content and count rate varied from one soil to another. At a moisture content of 0.6 inch of water per 6-inch soil depth, the maximum difference in soil moisture content among four soils was 0.16 inch; whereas, at a content of 1.5 inches, the maximum difference was 0.28 inch of water. One calibration curve could not be used for the 0- to 6-inch depth in all soils because of the large effect of soil texture on the escape of neutrons from the soil, but with careful depth control of the probe and uniform soil surfaces, a satisfactory calibration for the 0- to 6-inch depth was obtained for each soil. The results indicate that for most field studies it is desirable to use separate calibration curves for each soil under investigation. (SWC 9-g1)

C. Factors Influencing the Use of Moisture by Crops

1. Surface color. In connection with a microwatershed study at Fort Collins, Colorado, detailed measurements were made on the influence of the color of concrete between corn rows on the chlorophyll content, leaf temperature, transpiration rate, growth and yield of corn plants. Corn yields on rows 6.5 feet apart were 86 bushels per acre where the concrete between the rows was painted black as compared with 48 bushels per acre from areas where the concrete was painted white. The yield increase on the black treatment was related to higher soil temperatures in the spring, lower transpiration, and lower leaf temperatures. Plants in the plots with black concrete grew faster in the spring and matured earlier than those in the white treatment. The reflected radiation to the corn plants was six times greater from white surfaces than from black. Transpiration on the treatments with white surfaces was 50 percent greater. The chlorophyll content of the plants grown on the black treatment was 48 percent higher than the plants grown on the white treatment. These data suggest that the energy available to a corn crop under field conditions is probably not the factor limiting maximum plant performance. Although the above data do not give a complete understanding of the influence of radiation and other factors on the performance of the corn plant, they do represent a good beginning and help to define areas where emphasis should be placed in the future. (SWC 9-d1)

2. Influence of weed species. Little information is available concerning the root systems of the important weed species. Research at Bushland, Texas, concerned with determining the spatial extent and geometry of a number of annual weeds has derived some valuable information for developing weed control methods. Results showed the root depth of cocklebur (Xanthium pennsylvanicum), puncture vine (Tribulus terrestris), Russian thistle (Salsola kali), pigweed (Amaranthus retroflexus), and kochia (Kochia scoparia) was 9.6, 8.4, 5.9, 7.8, and 7.3 feet, respectively, compared with 5.6 feet for sorghum. Lateral root spread of the same species was 14, 11, 8, 6, and 11 feet, compared with 7 feet for sorghum. These data, incomplete as they are, suggest that weeds extract water from a much wider soil area than most crops and therefore, are serious competitors for moisture and nutrients. (SWC 9-e1)

3. Utilization of moisture by native range. In spite of the fact that 60 percent of the agricultural land in the Southern Plains States is in range and pasture, little research effort is devoted to soil and water problems on these important lands. A research study recently initiated at Bushland, Texas, to determine precipitation-soil moisture-shortgrass growth relationships under various clipping regimes, has given some insights into the water requirements of native range. During June, over 10 inches of rain fell, which is 7 inches above normal, wetting the soil to a depth of 3 feet. Three weeks later, the entire profile was devoid of water and the grass showed drought damage. Rainfall and soil moisture measurements suggest that the penetration of moisture from rains on rangeland is far less than that assumed from measurements made with infiltrometers and rainulators. (SWC 9-e1)

Increased concern in recent years about dust as an air pollutant has caused scientists to take another look at control systems. Earlier studies showed that crop residues are one of the most effective control tools. Studies are continuing at Big Springs, Texas, to evaluate the competition for moisture between a native grass species, used as a wind barrier, and cotton in various row patterns. Results show that although the seasonal use by grass and cotton is equal, the grass uses moisture at uniform rate during the growing season, whereas the requirements for cotton vary with the stage of development. The competition for water is reflected in yields. Lint cotton yields in rows 40 inches from the grass row have averaged 240 pounds per acre compared with 380 pounds in rows 80 inches from the grass row. These data are of value to action agency personnel concerned with developing wind erosion control practices. (SWC 9-e1)

4. Evapotranspiration of crops. Evapotranspiration studies initiated at Akron, Colorado, using eight simple and inexpensive lysimeters, are producing some interesting results. Continuous evaluation of evapotranspiration (ET) on native grass, fallow-wheat, sorghum, oats, and sudangrass during the year showed that evapotranspiration exceeded potential evapotranspiration many times during the season. These data suggest that considerable advective energy is used for ET even when plots are large and precipitation is the only source of water. Native range, a low-growing crop, extracted little additional energy from the air for ET, whereas sorghum and oats extracted considerable advective energy for ET. The data also indicated that the ET varied widely among different crops even though cover and soil water conditions were comparable. These data suggest that a great need exists for determining the plot size needed for accurately testing the influence of variables on ET. (SWC 9-d1)

5. The influence of plant growth stage on drought damage. The influence of stage of plant development on yield reduction by moisture stress has been clearly defined for such crops as corn, but not for small grains. In a field experiment with dryland barley at Riverside, California, moisture stress during the early jointing stage, approximately 5 weeks before heading, reduced grain yields. Adequate moisture from formation of the third joint

to maturity did not compensate for the early jointing stage deficiency. Moisture stress affected yields by reducing the number of kernels per head. These data suggest that with small grain the availability of water during critical periods of plant growth is likely to be more important than total seasonal moisture. (SWC 9-g1)

6. Growth retardants. Active studies have continued in a search for growth retardants that might reduce moisture use. In an experiment at Riverside, California, maximum reduction of corn leaf area was obtained by application of 800 p.p.m. of maleic hydrazide at tillering. Concentrations of 100 p.p.m. stimulated, rather than retarded, growth. Moisture relations in the 6-foot soil profile were the same for both the treated and nontreated plots. (SWC 9-g1)

7. Soil moisture levels. A continuing study at Akron, Colorado, to determine the effect of different quantities of stored soil moisture at seeding time on the water utilization patterns of millet and sudangrass has shown that water-use efficiency (the amount of dry matter produced per inch of water used) increased as the water use increased. Water use efficiency was increased from about 200 pounds per inch of water with 9 inches of water used to 300 pounds with 12 inches of water used. Beyond 12 inches of total use, the values were constant. These data suggest that subsoil moisture at planting time is extremely important for most crops in the Great Plains. (SWC 9-d1)

8. Grass varieties and row spacing. High production costs and favorable beef prices have caused renewed interest in grass seedlings and grass seed production in the Great Plains. At Sidney, Montana, the effects of row spacing on seed production and water-use efficiency of four introduced grass species are being studied. Grass forage and seed yields and water-use efficiency were greatest on the 30-inch rows in wet years and on the 42-inch rows in dry years. Nitrogen plus phosphorus fertilizer increased the water-use efficiency by 150, 175, and 200 percent for the 60-, 42-, and 30-inch spacing, respectively. Over a 3-year period, more than 500 pounds of seed per acre per year have been produced. These findings will have considerable significance in evaluating the feasibility of producing grass seed in the Northern Great Plains. (SWC 9-d1)

9. Rangeland seedbed preparation. The success of revegetating depleted rangelands and abandoned cropland has been very limited in the Central and Southern Great Plains, largely because of inadequate moisture in the seedbeds. Various fallow methods have been studied on cultivated McGrew loamy sand to be seeded to grass at Nunn, Colorado. Results from a 3-year study show that no water is conserved by a fallow system unless the seasonal rainfall is above average and all weeds are controlled. These data suggest that even with the use of the best management practices developed to date, it is difficult to conserve adequate moisture for grass seedings on sandy soils in the Central Great Plains. (SWC 9-d1)

10. Nitrogen fertilization. The question of the extent of crop damage from fertilization during periods of high soil moisture stress has not been satisfactorily resolved. Results of a study made at Riverside, California, to compare 15- and 60-pound nitrogen rates applied to barley at various moisture levels showed that the 60-pound rate reduced barley yields 20 to 25 percent and water-use efficiency by approximately 35 percent. This reduction occurred because leaf area on the heavily fertilized plots was 17 percent higher than on the low rate. These results emphasize the importance of adequately assessing the soil moisture regime before applying nitrogen fertilizer to dryland soils. (SWC 10-g2)

Studies to evaluate the influence of fertilizer on moisture use were continued this year at Pendleton, Oregon. Results show that the use of stored soil moisture in a 6-foot profile was 6.4, 7.9, and 9.2 inches where 0, 80, and 120 pounds of N were applied, respectively. The water-use efficiency was 6.5, 8.5, and 8.4 bushels per inch for the 0-, 80-, and 160-pound N rates. These again demonstrate the importance of fertilizer as a tool for fully utilizing the profile soil water in dryland regions. (SWC 10-f2)

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United States Department of Agriculture

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AREA 10: SOIL PROPERTIES, PROCESSES, AND MANAGEMENT IN RELATION TO THE CONSERVATION AND EFFICIENT USE OF LAND AND WATER RESOURCES

Problem: The soil is the source of the nutrients required for plant development. When chemicals are applied to the soil, they usually react with the soil before the plant uptake process begins. The nutrient ion finally is found in the top of the plant where it performs its metabolic function. To reach this end point, the ion passes through various chemical reactions, most of which are not understood.

Soil tilth and structure control many of the responses of the plant to soil management. Too often, visual improvement of the physical properties of the soil has been observed in the field, yet these physical attributes cannot be quantitatively described because of a lack of methods and procedures. The research progress on soil tilth is hampered by a lack of understanding of the forces involved in holding soil particles together in stable crumb structure. If an understanding of the factors was improved, our scientists could develop practical methods for exerting a real influence on the structure of our soils.

Recent improvements in the processes important in the nitrogen fertilizer industry have been or will be reflected in increased production and lower prices to the consumer. With the rapidly expanding use of N fertilizers, overapplication may be expected to become increasingly prevalent because little is known regarding intrinsic N requirements associated with specified levels of maximum production for most of the major crops. Among the problems which may arise from overuse of N are (a) reduction in crop quality, (b) possible accumulation in ground and surface water, and (c) waste of some important natural resources used in synthesis of N fertilizers.

In recent months, concern about water pollution from small quantities of soluble nitrogen and phosphorus has increased. Increasing the nutrient content of surface waters results in objectionable growth of algae and larger water plants (eutrophication). Fertilization of agricultural lands is suspected as one of the contributors. However, the amounts of nitrogen and phosphorus reaching waters that can be attributed to fertilization of agricultural lands are as yet largely unknown.

The amounts of insecticides and herbicides being used on agriculture lands continue to grow. Most of these compounds are applied to the soil, or ultimately reach the soil. The adsorption and persistence of these compounds in soils must be understood if soil pollution is to be avoided.

World population and food supplies are causing concern, and experts predict that food shortages are inevitable. Our only hope for meeting the world food requirements lies in new technology developed through research.

USDA AND COOPERATIVE PROGRAM

The Division program in this area involves microbiologists, chemists, physicists, and plant physiologists working on basic and applied problems associated with developing principles for soil and water conservation. The Federal scientific effort devoted to this research totals 81 professional man-years. Of this number, 27 are devoted to nutrient requirements -- uptake and balance; 23 to soil chemical properties; 22 to tillage, residue management, and cropping systems; and 9 to soil microbiology.

PROGRAM OF STATE EXPERIMENT STATIONS

A total of 378 scientific man-years is devoted to this research.

PROGRESS -- USDA AND COOPERATIVE PROGRAMS

A. Nutrient Requirements--Uptake and Balance

1. Recovery of applied nitrogen. Increased public concern in recent months about soil and water pollution has fostered a renewed interest in determining plant recovery of applied nitrogen. Results of studies at Huntley, Montana, show that sugar beets, bromegrass, and corn recovered up to 98 percent of the nitrogen applied at low rates (100 pounds per acre per year), but only 60 percent at nitrogen application rates of 200/lb./acre/yr. Further studies to evaluate the fate of the unrecovered nitrogen at the high N rates are being planned. (SWC 10-d2)

2. Mineralization of nitrogen. In a study at Corvallis, Oregon, to evaluate the stability of ammonia in soils, it was shown that losses of ammonia from air-dried ammoniated soils continue for a long time. After 15 months' storage of previously ammoniated samples, ammonia losses from 32 soils ranged from 7 to 43 percent of the initial ammonia content; after 5½ years' storage, losses from the same samples ranged from 26 to 53 percent. The losses are attributed to replacement of sorbed NH_3 by H_2O vapor in the air. Other laboratory work on ten different soils has shown that 2 to 18 percent of the organic carbon was solubilized in water after treating the soil with anhydrous ammonia. Similar amounts of carbon were solubilized from previously untreated soils by 0.15 N NH_4OH. These data should be of great interest to scientists concerned with determining ammonia in soils after storing samples for long periods of time. (SWC 10-f2)

The large quantities of nitrogen and other elements locked in the organic fraction of the soil have a big influence on plant nutrition. In addition, the physical, chemical, and biological reactions in soils are directly related to the organic fraction. In a continuing fundamental study at Corvallis, Oregon, on the chemical constituents of soil organic matter, results indicate that controlled potential coulometry can be a valuable technique for determining the aromaticity of partially oxidized humic materials. Through use of this technique, the number of electrons, probable mechanisms and reaction products involved in reduction of aromatic nitro compounds in nonaqueous solvents have been determined. These findings add to our limited knowledge of the organic constituents present in soils. (SWC 10-f3)

Experiments concerned with improving methods of organic matter determination and the constituent separation of this important compound have also continued at Fort Collins, Colorado. In studies of the chemistry of humus fractions of soils, various factors such as concentration, excitation, temperature, and composition of the solvent affect the fluorescence of humic acid colloids. Increasing the water content of the organic solvents had a marked quenching effect on the fluorescence produced by the colloids. Fluorescence intensity is proportional to the concentration of humic acid colloids below 100 p.p.m. By comparison with known organic compounds, it is suggested that the fluorescence of humic acid colloids is due to "n -π " electron transitions. (SWC 10-d2)

The decomposition of organic residues and the release of plant nutrients are still not understood. A study initiated in 1965 at Twin Falls, Idaho, to determine the influence of grain variety and nutrition on decomposibility of the straw and to follow the decomposition process has shown that large ion gradients exist in the soil surrounding decomposing layers of barley straw and corn stover. The presence of the ammonia and nitrate gradients depended on the nitrogen content of the decomposing residues. When the N percentage of barley straw was 2.10, high concentrations of ammonia and nitrate extended into the soil for distances greater than 2 cm. When the N percentage was 1.76 or less, no ammonia gradient was found. Under the latter condition, the nitrate-nitrogen gradient was reversed and nitrate moved from the soil into the straw to supply the nitrogen needed for the decomposition process. These data, though preliminary, suggest that the nitrogen availability in a soil with residue incorporated will depend on the chemical composition of the residues added. (SWC 10-f3)

The search for an explanation of the poor recovery of nitrogen from grassland soils continues. At Mandan, North Dakota, in a greenhouse experiment, the N recovered by bromegrass plus that present in the soil at the end of the experiment was less than 70 percent of that applied. This loss was assumed to be by volatilization because none was lost by leaching. These data again point out the need for some carefully controlled studies of the fate of N applied to soil. (SWC 10-d2)

At Auburn, Alabama, in a search for the cause of the toxicity to seedling cotton roots, several crop residues were decomposed in the soil. Results showed that the chief cause of toxicity of decomposing sorghum, peanut, and alfalfa residues to cotton germination and seedling cotton root growth was the occurrence of nonionized NH_3 formed during microbial decomposition of nitrogenous components. Toxicity occurred when 100 p.p.m. or more of ammonium N was found in the soil at a pH of 8 or above. Alfalfa alone appeared to contain an organic toxin capable of directly affecting germination and seedling growth. Results from this study will be useful in developing residue management practices for wind and water erosion control. (SWC 10-b6)

Experimental techniques in the past have not been successful in separating plant uptake of soil nitrogen and fertilizer nitrogen. During this year at Beltsville, Maryland, such a separation was accomplished by suspending soil containers planted to sudangrass over nitrogen solution in beakers. Uptake of soil N ranged from 69.5 mg. to 148.6 mg. for the 0- and 240-mg. levels of fertilizer N, respectively. These results agree with previously defined N immobilization concepts. Similar experiments will have to be conducted with other soils to evaluate the validity of these data. (SWC 10-36(a3)).

3. Nutrient requirements for various crops. A method of estimating the minimum uptake of nitrogen per unit of dry matter produced at maximum yields was developed during the year at Beltsville. With this procedure, it appears that the nitrogen requirements for a number of important crops can be estimated from a knowledge of the relationships between dry matter and nitrogen yields in the range of deficiency to luxury consumption. One of the more obvious uses of the N requirement is in evaluating adequacy and efficiency of N fertilizer application practices. With the increased concern about the accumulation of nutrients in water supplies, agriculture should find the concepts developed in this study most valuable. (SWC 10-aB2)

During 1965, a year with adequate rainfall, nitrogen fertilization greatly increased yields of corn and bromegrass. For bromegrass, nitrogen fertilization resulted in a sevenfold increase in yield without changing the water required to produce the crop. This illustrates the effect of proper fertilization on the efficient use of water. At Sidney, Montana, the effects of row width and fertilizer treatments on yield and water-use efficiency of different grass species were studied. Forage production, as well as water-use efficiency, was nearly doubled by nitrogen and phosphorus fertilization. The effect of fertilizers on forage production decreased as row spacings increased. (SWC 10-d3)

The problem of efficiently using nitrogen on short-season, heavily irrigated pastures has not been solved. Studies conducted on a mountain meadow near Big Piney, Wyoming, showed that three nitrogen sources (urea, $(NH_4)_2SO_4$ and NH_4NO_3) essentially increased forage yields the same.

Regardless of climatic and varying irrigation conditions, 80- and 160-pound N increased forage yields approximately 1.0 and 1.5 tons per acre, respectively. Crude protein did not vary significantly between the 80- and 160-pound N-fertilized forage. Nitrogen recovery from urea and NH_4NO_3 at the 80-pound N level was significantly better than from $(NH_4)_2SO_4$. These results will be very useful to ranchers in developing fertilizer systems for this important forage area. (SWC 10-d3)

Nutrient uptake studies conducted over the past several years in the South have shown that the N requirement of cotton is heaviest from the early square to the late boll stage. These data and the possibility of loss by leaching have caused scientists to question the heavy early applications that are commonly made. Results from Watkinsville, Georgia, indicate that no loss in cotton yield occurs if N applications are delayed until after the start of blooming. Nitrogen deficiencies can be corrected by N applications as late as the heavy blooming season without yield loss. (SWC 10-b3)

The potassium chemistry of the mountain soils of Puerto Rico has never been understood. In field studies in Puerto Rico, results showed that the major mountain soils can supply up to 400 pounds of K per year to intensively managed pastures. Exchangeable and hot-nitric-acid extractable K did not reflect the high K-supplying power of these soils. Results from these studies suggest that the amount of K added to pastures could be reduced by one-half without sacrificing yield. (SWC 10-b4)

Studies initiated at Cherokee, Oklahoma, to assess the value of legumes in a rotation indicate that continuous wheat receiving 40 pounds of N per acre per year will yield as much as wheat in an alfalfa rotation. However, at Temple, Texas, grain sorghum in a sweet clover rotation yielded one-third more than continuous sorghum receiving 60 pounds of N per acre per year. These and other data suggest that legumes as grass rotation are of little value in most of the Great Plains, but can be of value in the higher rainfall areas, such as the Texas Blacklands. (SWC 10-e2)

In laboratory studies at Weslaco, Texas, concerned with developing methods for predicting nitrogen requirements, cabbage did not respond to applied N when the nitrate N content of the surface 12 inches of soil was greater than 20 pounds per acre. In these studies, the plants obtained all of their N from the surface 2 feet of soil. (SWC 10-e2)

At Twin Falls, Idaho, a marked decrease in the efficiency of nitrogen fertilizer use by sugar beets was noted under excess irrigation. Over-irrigation reduced yields most on low nitrogen treatments. As much as 95 lb. of nitrate-nitrogen per acre was leached below the 3.5-foot depth when irrigation was excessive. These data emphasize the effect that good water management practices have on the efficiency of nitrogen use. (SWC 10-f2)

The problem of a decline in the quality and quantity of potato production in Idaho has been of concern to the producers for some time. Results from an experiment initiated at Twin Falls, Idaho, this year to determine the effects of N, P, and irrigation on the yield and quality of potatoes, suggest that quality can be maintained if moderate rates of fertilizer (160 pounds N and 35 pounds P) are used but that amounts in excess of the plant needs cause undesirable characteristics in potatoes. (SWC 10-f2)

In recent years, European scientists have become very concerned about the influence of high sodium and chloride on the quality of sugar beets. In studies conducted at Logan, Utah, to evaluate the influence of certain cations and anions on the yield of sugar beets, results showed that yield and quality were not reduced by high sodium levels in the soil if adequate sulfate was present. (SWC 10-g1)

An attempt to find a solution to the important problem in the Northeast of successfully achieving seedings of grass-legume mixture and maintaining the legume in mixed swards continues. At University Park, Pennsylvania, results of previous work suggest that competition for nutrients and light can be eliminated. Competition studies conducted during the last year, using nutrient solution culture, show that the possibility of grass roots excreting toxic compounds to legume roots is very remote. Field study results support previous evidence that legume yields are much higher when legumes and grasses are seeded in alternate rows 7 inches apart than when mixed in the same row. (SWC 10-a2)

Studies at Fort Collins, Colorado, on the release of soluble soil phosphorus and the movement of phosphorus to and into plant roots have continued. Results from this year's studies show that the rate of release of the solid-phase phosphorus to the soil solution is not the limiting factor in the absorption of phosphorus by plant roots. (SWC 10-d1)

The ability of the soil to provide plants with adequate amounts of phosphorus depends on both the state of the phosphorus in the soil and the rate of its supply. When a phosphatic fertilizer is applied to the soil, it undergoes several reactions before it is consumed by the plant. In a PL-480 study in Israel, the influence of exchangeable soil ions on the solubility of low solubility phosphates was studied. Results showed that when clay particles contain a reasonable amount of mono-valent exchangeable cations, the solubility of hydroxy-apatite increase significantly. These results suggest that the usual handbook solubility values are not simply applicable to soil systems. (A10-SWC-38)

In a study concerned with developing the best system for fertilizing native grass at Mandan, North Dakota, results show that the yields per pound of N were about the same for the treatment that received all of the N in one treatment for the 6-year period, as compared with the treatment getting the same amount applied annually. Laboratory studies suggest that benefit

of residual amounts result from unused N in the soil profile. These data are of great importance in this area where there is marginal economical return from range fertilization. (SWC 10-d2)

A study has been initiated in Israel under the P1-480 system to evaluate the importance of fertility in improving the conditions for crops growing on saline substrate. At salinity levels up to 5 to 7 millimhos/cm., various fertilizer formulas led to increase in Foxtail millet yields up to 80 to 90 percent of those occurring on nonsaline soil. No differences between the effects of N and P were noted at this salinity level. At higher levels (11 mmhos/cm.) phosphorus played a key role in promoting plant adaptation. (A10-SWC-1)

4. Subsoil nutritional needs. Exposed subsoils and lateritic soils in the humid tropics, if properly managed, have a large production potential. The application of 8 tons per acre of a sugarcane byproduct, filter press cake, greatly accelerated establishment of Pangola grass on a heavily fertilized Alonso clay subsoil in Puerto Rico. Once the grass was established, the well-fertilized subsoil produced almost as high yields of forage as did the well-fertilized topsoil. Pangola grass growing in subsoil responded strongly to N, P, and K applications. These data are of importance in stabilizing cuts and fills in roads and bench terraces, and in reclaiming severely eroded areas in the mountain region. (SWC 10-b2)

The lower horizons of the soil profile are frequently exposed during the construction of level bench terraces. At Sidney, Montana, spring wheat yields on unfertilized exposed areas averaged 310 pounds of grain per acre per year as compared with 1407 pounds on exposed areas fertilized with 60 pounds of N annually. Yields on the part of the bench receiving 1 to 2 inches of surface soil were 30 to 500 pounds per acre more than the fertilized exposed areas. The reason for the large increase from the topsoil treatment was not evident. (SWC 10-d3)

Studies on an exposed Pullman soil at Bushland, Texas, substantiated earlier findings that adequate fertilizer can compensate for up to 8 inches of topsoil removed. (SWC 10-e2)

The results of two field experiments conducted at Prosser, Washington, and in the Columbia Basin indicate that when calcareous subsoils are first brought under production, high rates of P fertilization are required to produce high-yielding crops. The residual effects of phosphorus fertilization rates above 200 pounds P per acre will suffice for two or more subsequent crops. Application of 260 pounds of P per acre supplied adequate P for high yields of four crops; 130 pounds of P per acre were adequate for only three crops. Sodium bicarbonate-soluble P proved useful for evaluating the carryover from previous P applications. (SWC 10-f2)

At Blacksburg, Virginia, results obtained the first year in an experiment on Groseclose silt loam from which the topsoil was removed indicate that soil crusting and associated problems of water conservation are major problems on exposed subsoils. A straw mulch prevented soil crusting, conserved water, and produced corn yields almost as high as on plots where the topsoil was not removed. The data from this study and those mentioned above suggest that the productivity of the areas exposed by land forming can be restored, providing the proper treatment is applied. (SWC 10-a1)

5. Micronutrients. In a continuing study at Fort Collins, Colorado, the levels of ribonuclease activity in corn plant tissues at different zinc and iron levels were determined in an effort to learn more about the effect of minor element concentration on the plant metabolic function. Results showed zinc-deficient plants had a higher ribonuclease activity than the untreated plants. Zinc additions corrected the deficiency symptoms and lowered the ribonuclease activity. (SWC 10-d1)

Also at Fort Collins, Colorado, studies on the influence of sulfur on residue decomposition and plant yields showed that wheat growth on NPK-fertilized soil in the greenhouse was depressed if the S content of the straw mixed with the soil was less than 0.15 percent. When fertilizer S was added with the NPK fertilizer, or when the S content of the straw exceeded 0.15 percent, the straws had no effect on yield. Ratios of total N to total S (weight basis) and protein N to protein S were determined on the wheat tissue. While total N-S ratios varied from 8 to 30, the protein N-S ratios were 15 for all treatments. A total N-S ratio of about 15 or less suggests adequate S, but a greater ratio indicates that S is limiting protein formation. This ratio concept also was applied successfully to a field study of sugar beets at Prosser, Washington. Future studies will obtain N-S relationships on other important crops. (SWC 10-d3)

The yield of Gaines wheat grown near Pendleton, Oregon, continues to show benefit from sulfur applied as gypsum in 1959. In a wheat-pea annual cropping system, 15 pounds of sulfur per acre have furnished adequate sulfur for three pea crops and 4 wheat crops. The average yield increase for the four wheat crops resulting from the sulfur application is 6 bushels per acre. (SWC 10-f2)

Experimental results obtained in 1965 at Prosser, Washington, suggest that the occurrence of zinc deficiencies of crops following sugar beets, reported in 1962 and 1963, is short lived. In 1963, corn following sugar beets was severely zinc deficient; however, Red Mexican beans grown in 1964 and corn in 1965 showed no deficiency symptoms. (SWC 10-f1)

As a result of research findings at Prosser, a large number of zinc fertilizer compounds are now available in the Columbia Basin. These

compounds vary in chemical composition and size of granules. Five sources of zinc (zinc sulfate, zinc oxide, zinc ammonium sulfite, zinc-polyflavanoic, and zinc-EDTA) were compared on Pinto beans grown in the Basin. All zinc carriers, regardless of the rate used, eliminated visual zinc-deficiency symptoms on the beans. All carriers were not equally effective at a given rate, however, in furnishing zinc to the crop. Two pounds of zinc per acre as the chelates, 5 pounds of zinc as zinc sulfate or zinc ammonium sulfite, and 15 pounds of zinc as zinc oxide were equally effective in increasing the zinc concentration in the foliage at early bloom stage. (SWC 10-f1)

Because zinc fertilization is a standard practice in the Basin, it is possible over a period of years to increase the zinc concentration in the soil to a point of toxicity to some plants. In a study to define what these rates might be, 200 pounds zinc per acre applied over a 2-year period to a neutral soil did not induce toxicities with corn or grain sorghum. These results suggest that polluting the soil with zinc at rates now recommended (12 pounds every 3 years), is not an immediate problem. (SWC 10-f1)

Studies have continued in Poland to evaluate the distribution of trace elements in rocks as related to micronutrients in plants. Results show that most of the micronutrients in the soil (nickel, copper, zinc, and molybdenum) were found to be concentrated in the coarse clay and silt fractions rather than in the fine clay. These observations contribute significantly to the information that must eventually provide a basis for our ability to predict micronutrient distribution of soils from a knowledge of weathering processes and parent rock composition. (E21-SWC-7)

B. Soil Chemical Properties

1. Soil acidity and plant growth. Studies concerned with defining the soil pH level at which cotton roots are inhibited, and with identifying the specific factors concerned, are continuing at Auburn, Alabama. Results from completed studies suggest that pH per se does not inhibit root growth above 4.5. The response to lime application can be explained on the basis of chemical activity of the aluminum in the displaced soil solution. Maximum yields were obtained when lime was applied to both the surface and subsoil. Results from these studies indicate that lime must be applied to acid subsoils if roots are to have access to subsoil moisture. Future studies will be concerned with developing a simple technique for placing lime in the subsoil. (SWC 10-b6)

Field observations made throughout the Coastal Plains show that most field crops in this area are very shallow rooted. This shallow rooting causes crops to suffer from drought damage even when the subsoil has available soil moisture. During the last year, detailed root distribution studies of corn growing on Coastal Plains' soils were made near Florence, South

Carolina. Results showed that 97 percent of the roots in the Norfolk soils, the most extreme case, were in the 0- to 8-inch depth. Corn on the Lakeland, Goldsboro, and Dunbar soils also had shallow root systems. Experiments are now underway to determine which soil properties are limiting to root development. (SWC 10-b6)

Previous plant aluminum tolerance studies conducted with wheat and barley at Beltsville, Maryland, suggested that the roots' ability to change the pH accounts for the differential tolerance. Studies made this year established that not only do aluminum-sensitive plants maintain the nutrient solution at lower pH levels, but they also accumulate higher concentrations of aluminum in their roots than do tolerant varieties. During the year, 15 varieties of soybeans and 14 varieties of cotton were screened. Results showed soybean varieties varied widely in their tolerance to high aluminum. All cotton varieties, however, were susceptible to both aluminum and manganese toxicities. (SWC 10-aB8)

In a continuing study at Beltsville, Maryland, on the factors affecting limestone efficiency, the application of phosphorus reduced the efficiency of coarse limestone but had no influence on that ground fine. With the coarse material, the reduction in efficiency amounted to a difference of up to 0.7 of a pH unit. (SWC 10-aB7)

Several procedures for measuring root elongation under field conditions have been evaluated at Auburn, Alabama. Experience indicates that root behavior, both with respect to toxicities and deficiencies, can be estimated with reasonable accuracy using a glass front box technique. This technique is direct, rapid, and avoids the questionable and time-consuming task of recovering roots from soil. (SWC 10-b6)

Limestone applied over a 4-year period to heavily fertilized grasses growing on Catalina clay in Puerto Rico had a pronounced effect on yields of subsequently planted sugarcane. Yields increased from almost zero in the unlimed or lightly limed plots to more than 40 tons per acre in the plots well limed. Surface liming with 4 tons per acre before planting sugarcane sharply increased cane yields, but these remained lower than when the soil had been adequately limed while in forages. The data suggest that inadequate liming may be one reason for low cane production in Puerto Rico's humid region, which has prevented the Island from meeting its sugar quota at a high cost to the economy. (SWC 10-b1)

2. Soil pesticide complex. At Fort Collins, Colorado, progress has been made in studying the effect of chlorinated pesticides on soil metabolism and enzymatic activity, the movement of pesticides in soil, and the adsorption of pesticides on organic colloids in soil. Studies initiated to evaluate the effects of insecticides on microbial activities in soils with different properties have progressed during the year. (SWC 10-40(d7))

In a microbial activity study, DDT, lindane, and dieldrin reduced the rate of cellulose decomposition in soil when added at rates of 125 p.p.m. or more, but had no effect when added at the rate of 25 p.p.m. Although cellulose decomposition was delayed by lindane, this chemical appeared to have no effect on the rate of alfalfa decomposition. Nitrification of urea was severely inhibited by concentrations of lindane above 1 p.p.m., but only slight effects of DDT and dieldrin were noted even at concentrations as high as 250 p.p.m. Only dieldrin reduced the oxidation of elemental sulfur. Urease activity in a Fort Collins loam was not inhibited by rates of 1 to 1,000 p.p.m. of lindane, heptachlor, DDT, or endrin. (SWC 10-40(d7))

In an evaluation of the importance of the adsorption or reaction of soil organic constituents or similar compounds with insecticides and their transformation products, results show that neither lindane nor DDT was adsorbed from a hexane solution by humic acids extracted from Leonardite. However, when the hexane was volatilized at room temperature, lindane and DDT were retained by the colloids. Increasing temperatures lowered the amount of pesticide recovered from the Leonardite humic acid colloids. At room temperatures, DDT was completely recoverable, but after heating the DDT samples to 100° C., more than 50 percent was lost. The decreasing recoveries of pesticides with increasing temperatures suggest that physical forces exist between the pesticides and organic colloids, and that these physical forces retard volatilization of the pesticide. (SWC 10-40(d7))

In laboratory experiments to determine the effects of continuous leaching on the movement of pesticides in soils, the downward movement of lindane applied to the soil surface was influenced by soil texture and the amount of water applied. However, for all treatments, more than 99 percent of the pesticides remained in the top 6 cm. of soil. Extremely small amounts of lindane were detected at depths of from 6 to 18 cm. In addition, only 0.1 to 0.3 p.p.b. were found in the water leachate. There was no movement of DDT, regardless of the soil used or the amount of water applied. These data suggest that movement of the chlorinated hydrocarbons by leaching is nil in soil. (SWC 10-40(d7))

A preliminary laboratory study conducted to determine if DDT could be decomposed in soils by increasing the microbial activity with various amounts of alfalfa meal, showed that DDT was completely decomposed after 2 weeks' incubation under anaerobic conditions. Analysis suggested that DDT was the main decomposition product, but that other decomposition products may be involved. Although further experimentation under very carefully controlled conditions is required to clarify the findings, these results are most exciting. A method for reclaiming soils polluted with DDT might be developed from the data collected in these studies. SWC 10-40(d7))

In another study, concerned with assessing the contribution of soil organic matter to pesticide adsorption in soil, removing organic materials from soil by organic solvent extraction reduced the soil's capacity to adsorb lindane. Infrared analysis of petroleum ether extracts of soil showed only aliphatic patterns with no functional groups. Infrared analysis of the benzene extracts from soil showed characteristic aliphatic, aromatic, and carbonyl patterns. These data suggest that the organic fraction in the soil plays an important role in pesticide adsorption. (SWC 10-40(d7))

During the year, analytical techniques and methods for determining pesticides in soils were perfected at Beltsville, Maryland. A combination of procedures was developed simultaneously. These include thin-layer chromatography, gas chromatography, and infrared and ultraviolet spectophotometry. As little as 0.1 nanogram of pesticides can be detected by electron capture on the gas chromatograph. Confirmation by infrared can be accomplished with as little as 2 micrograms of pesticide. (SWC 10-aB9)

Studies have been initiated to determine the agricultural significance of certain transitional elements, such as "heavy metals," derived from pesticides and agricultural chemicals. These elements enter the cycle as contaminants in commercial fertilizers, constituents of certain pesticides, and atmospheric contaminants. A perfusion technique is being used to study the chemistry of lead, mercury, and cadmium in soils. This technique permits the continuous cycling of a discrete amount of solution through a two-section column. The upper section contains the soil to be studied and the lower section contains an exchange resin. The small amounts of the elements removed from the soil by the extracting solution are retained and concentrated on the exchange resin in a form suitable for subsequent removal and quantitative determination. Very sensitive and precise analytical procedures are required to determine the small amounts of the transition elements that may be present in plants. Atomic absorption spectrometric techniques are being developed for this purpose. (SWC 10-39(aB12))

The problem of recovering known concentrations of herbicides applied to soils has been of concern to soil chemists for some time. Results of a study concerned with refining the methods for determining herbicides in soils at Watkinsville, Georgia, showed that neither atrazine nor simazine was significantly adsorbed from dioxane solution by absorbents such as neutral alumina, silica gel, charcoal, and a Cecil soil. These results suggest that dioxane offers promise as a satisfactory extractant for simazine and atrazine under a variety of conditions. These pesticides were extracted from a Cecil soil with near 100-percent recoveries. At Thorsby, Alabama, there was no residual effect from atrazine (applied annually during the 3 preceding years) on seedling emergence and growth of cotton or soybeans. (SWC 10-b5)

3. Radioactive fallout. In a continuing study concerned with minimizing the potential hazards from radioactive fallout in soils and plants at Beltsville, Maryland, the exchange reaction of clay was found to be important in determining the relative availability of different ions, including radionuclides, for uptake by plants. In a cation-exchange model study, rubidium had a greater tendency to form ion pairs with the clay surface than did sodium. On rubidium-saturated kaolinite or montmorillonite, about 80 percent of the adsorbed ions formed pairs; on sodium-saturated clays, about 30 percent formed ion pairs. The entry of some ions into less readily exchangeable or "fixed" forms in soils may greatly reduce their availability for uptake by plants. In soils from the southeastern United States, 30 percent of the total Sr-90 may be "fixed." Laboratory experiments with clay minerals and hydrated sesquioxide gels show a much lower degree of strontium fixation, so that the mechanism of fixation in soils remains unknown. The laboratory fixation and release of fixed strontium occur at similar rates, apparently measurable in terms of days. (SWC-AEC-0-0-1)

The deposition and retention of fallout on plants are of great interest because of the possibility of radionuclide contamination in food crops and, at high levels of contamination, radiation damage to plants. Field data show that wheat retained only 1 percent of the Sr-90 deposited in rainfall between heading and harvest. Leaves of plants that were easy to wet, such as coleus, sorghum, and rhubarb, retained up to 90 percent of the Sr-85 from droplets that had dried on the leaf surface. Under the same conditions, leaves that were difficult to wet, such as cabbage and beet, retained only 10 percent. With all species, retention decreased with decreased relative humidity and temperature of the air to which the leaves were exposed for 24-hours after the Sr-85 solution became dry. (SWC-AEC-0-0-1)

The effectiveness of deep plowing for reducing the uptake of radioactive strontium from the soil is under investigation. A large moldboard plow has been used to turn contaminated surface soil deep in the profile. With careful operation, 95 percent of the contamination may be buried deeper than 2 feet. This depth of placement has not proved adequate for greatly reducing the uptake of radiostrontium by crops, unless a chemical such as sodium carbonate is also buried to prevent root growth in the contaminated soil. Preparations have been made for testing yields and uptake of Sr-85 by several crops in 1966 after simultaneous plowing under of Sr-85 and sodium carbonate. (SWC 10-c3)

C. Tillage, Residue Management, and Cropping Systems

1. Soil structure. Providing structural stability to soil is the key to a number of agronomic problems facing agriculture. Structure stability in a natural soil system is related to the total amount and state of degradation of the organic materials present. Within the last decade,

soil scientists have shown a new interest in the factors contributing to the strength and stability of soil aggregates. An attempt to correlate and possibly extend the viscosity data with modulus of rupture measurements made on dried particles has been made at St. Paul, Minnesota. Viscosity studies have shown sodium clays are more viscous than calcium clays. Complexes formed of montmorillonite and noncharged dextrans had higher viscosities than the clay alone, with sodium clay complexes acquiring a higher percentage increase. Appreciable differences were found in the properties of reference clay minerals which could be traced to variations in samples as supplied by the vendor, as well as to different pretreatments. The method does show great promise as a comparative technique for assessing binding forces and mechanisms between clays and polymers. (SWC 10-c3)

In studies initiated at Madison, Wisconsin, to determine the changes in the character of the organo-clay complexes of soils as a function of change in soil type, properties and former management, it was found that methylation and reduction treatments to inactivate the functional properties of the organic component of the complex did not block residual clay exchange sites. These data also suggest that methylation of functional groups on the organic component do not block or otherwise sterically hinder clay exchange sites. (SWC 10-c3)

Observations made by farmers and technicians indicate that excessive soil strength will hinder establishment of grass stands in the Southern Plains. In a study at Big Spring, Texas, bulk density of Amarillo fine sandy loam soil compacted in 1963 to a density of 1.90 or higher remained at this level through 1965. The density of Amarillo soil deep plowed in 1963 increased from 1.55 to 1.68 from 1963 to 1965. This illustrates two problems associated with moderately-coarse-textured soils in moisture-deficient areas: (1) Once the soil is compacted, it does not change appreciably by wetting and drying or freezing and thawing without mechanical disturbance and (2) it increases in density with time after loosening and may reach a critical density level without added compaction. (SWC 10-e1)

The alluvial soils of the Imperial Valley of California are composed of highly stratified Colorado River deposits. A study of the relationships between soil texture and physical and chemical properties of the major soils of Imperial Valley conducted at Brawley, California, indicate that variations in the soils are due mainly to textural differences caused by the manner and sequence in which the alluvial material was deposited. Mineralogical analyses showed the clay fraction to be of uniform composition with approximately 42 percent montmorillonite, 29 percent mica, and 16 percent quartz and feldspars, with lesser amounts of chlorite, vermiculite, and amorphous materials in all soils regardless of soil texture. Fractionation of the soil phosphorus compounds indicated them to be mainly calcium phosphates with only small amounts of iron and aluminum phosphates.

This evaluation of the relationship between soil texture and the physical and chemical properties will be useful in developing better soil and water management practices for the crops grown on these soils. (SWC 10-g1)

2. Tillage. Results of a 10-year tillage study in northwest Iowa show that effectiveness of any tillage method is largely dependent on the amount of rainfall received. In years of deficient moisture, highest yields were produced using tillage methods that favored moisture conservation, such as listing. In years of sufficient moisture, yield differences between tillage methods were small. (SWC 10-c3)

Results of a 9-year study on the effect of various tillage practices on the yield of corn on Grundy silt loam near Beaconsfield, Iowa, indicate that treatments in which the soil is plowed -- conventional and wheel-track methods -- yield more corn than those that do not involve plowing -- mulch tillage, ridge planting and listing -- regardless of the climatic conditions. Chemical weed control was most effective when used in combination with tillage methods involving plowing. (SWC 10-c2)

Aggregate size and bulk density are the soil physical properties directly altered by tillage. Since these properties affect soil moisture relations, it is important that we obtain information regarding their physical and chemical properties. At Ames, Iowa, analysis of aggregates of Marshall silty clay loam indicated that particle size distribution was practically unaffected by plant residue treatments. Aggregate interiors were found to have higher cation exchange capacities, organic carbon, and total nitrogen than the aggregate exteriors. Studies of aggregate fabric will yield information leading to a better understanding of phenomena occurring in soils such as water stability, erosion, crust formation, nutrient availability, root proliferation and microbial activity. (SWC 10-c2)

Also at Ames, in a study to determine the rate of water infiltration into soils, the changing characteristics at the surface during periods of rainfall have been measured. Techniques have been developed to determine the water potential-water content-water diffusivity relations for thin samples of surface crusts. Laboratory studies showed that increasing the bulk density decreased total volumetric moisture retention, decreased retention at suctions less than 5 to 10 cm. of water, and increased retention at higher suctions. On a mass basis, there was little difference in moisture retention at higher suctions, indicating that in structurally stable systems of this type, most of the effect of bulk density is due to changes in size distribution of pores between aggregates. (SWC-10-c2)

At Blacksburg, Virginia, and Marcellus, New York, excellent yields of corn were produced over a 6-year period in undisturbed sod that was killed with herbicides. Soil temperatures early in the spring were lower under the mulch, but yields of corn compared favorably with yields on unmulched plots.

Farmers are particularly interested in the time-saving features of the practice. Results indicate that corn may be grown for 2 consecutive years, or possibly more, without tillage. (SWC 10-a1)

Studies were conducted in Virginia to evaluate separately the effects of the no-tillage and of the dead mulch on soil temperature, water conservatic and plant growth. The data indicate that the success of the practice on water conservation is associated primarily with the beneficial effect of the mulch. Runoff during the growing season was less than 1 inch both from the no-tillage plots and plots that received conventional tillage but were protected by a heavy straw mulch. Losses from unmulched plots were more than 4 inches. The unmulched treatments included plots with conventional tillage and plots on which the sod was killed with herbicides and removed from the plot. (SWC 10-a1)

At Presque Isle, Maine, continuing studies on seedbed preparation for potatoes indicate that efficiency of production may be increased by eliminating several tillage operations. Yields of both Katahdin and Russet Burbank varieties were not significantly different for reduced tillage and for conventional plowing and harrowing. Several reduced-tillage treatments were included, one of which consisted of a once-over operation where potatoes were planted with no prior seedbed preparation. (SWC 10-a1)

In Puerto Rico, the zero tillage method for plantain and tobacco productio has been extended to other crops. The yields of several crops were the same on three soils with and without tillage. Four herbicides and eight crops were studied. Results indicate that zero tillage systems hold great promise for conservation and better crop production in the mountain region In a study with yams, staking sharply increased yields by increasing yam size. Yields increased with plant populations up to 7,300 plants per acre Planting in beds increased yields of staked yams and decreased the number of broken and deformed tubers. (SWC 10-b5)

Restriction of root development by dense soil zones (pans) is a serious problem in the Atlantic Coastal Plains soils. In exploratory studies at Auburn, Alabama, using equipment which broke the traffic pan, prepared the seedbed, and applied herbicides in one pass, cotton yields were higher and subsoil moisture utilization was improved at four of the seven test locations. On the basis of 1 year's exploratory tests, this tillage metho with certain further modifications, appears to hold real promise for improving subsoil moisture utilization by various crops. (SWC 10-b6)

3. Profile modification. The interest in determining the effect of thoroughly mixing the soil profile on plant growth and nutrient uptake continues. At Bushland, Texas, mixing the profile of a Pullman silty clay loam to a depth of 5 feet in the fall increased sorghum yields 84 percent in 1965, when moisture was limiting. When adequate water was supplied, profile modification did not affect yields. In the modified profile treat ments sorghum extracted moisture from depths of 6 feet. Breaking up the

dense soil layer of Pullman soil appears to enhance moisture storage in the profile. (SWC 10-e1)

Also at Bushland, Texas, deep tillage, profile modification, and applied nitrogen increased yields of sugar beets. Beets grown on plots tilled 6 inches deep yielded 14.3 tons per acre; whereas those grown on plots tilled 12 inches deep and on plots with profiles modified to a depth of 2 feet yielded 18.4 and 22.6 tons per acre, respectively. The size and shape of the sugar beets were modified by the tillage treatment. Beets on the deep-tilled plots were larger and longer and had no branched roots. Applied nitrogen increased beet yields on all tillage treatments but produced largest yield increases on the 12-inch-deep tilled plots. Phosphorus fertilizer did not affect beet yields. (SWC 10-e2)

In continuing studies near Rockford, Washington, wheat yielded 30 bushels per acre where the land was conventionally plowed, 35 bushels per acre where mixed with a backhoe to a depth of 18 inches, and 58 bushels per acre where the profile was mixed to a depth of 48 inches. The increased yields were attributed to an enlargement of the effective soil water reservoir by the profile modifications. Approximately 80 percent more water was extracted from the deep-backhoe than from the shallow-tilled treatment. (SWC 10-f1)

Further evaluation of profile modification of Houston Black clay at Temple, Texas, substantiates the results obtained in 1964. Again the incidence of cotton root rot was reduced, but the causal factor or factors for this reduced incidence is more likely to be improved moisture-aeration relations for either the cotton plant or organisms antagonistic to the root rot fungus than soil desiccation, as was believed previously. (SWC 10-e1)

4. Mulches. Studies concerned with increasing the soil temperature early in the season by the use of mulch are continuing at Prosser, Washington. In the spring of 1965, sugar beet seedlings emerged approximately 2 weeks earlier where the rows were sprayed at seeding time with asphalt than where the soil was left bare. Soil temperatures at the depth of planting were about 6° F. higher under the mulch during the daytime. Nighttime soil temperatures were about the same for both treatments. Sweet corn planted about April 15 showed only minor differences resulting from the two treatments. (SWC 10-f1)

In Puerto Rico, various mulches and tillage practices are being studied on intensively managed coffee. Mulching the rows with coffee pulp or grass, with a grass cover crop between the rows, about doubled the yields. The mulch reduced the soil temperature, increased the available soil moisture during the dry season, increased the K content of the leaves, and increased the P content of the leaves during the dry season. (SWC 10-b5)

Studies continue at several locations in the Great Plains in an attempt to determine the factors that reduce wheat yields under a stubble mulch system. At Akron, Colorado, rates of residue had little influence on soil nitrate levels through the fallow period, but at North Platte, Nebraska, and Sidney, Montana, the nitrate-nitrogen content of the surface 3 feet was decreased by increasing rates of residue. When fertilizer was added, there was no marked difference in nitrates between any of the treatments at any location. (SWC 10-d5)

Temperature measurements made just below the soil surface on treatments with and without residue revealed a lower temperature under the mulch. At Sidney, Montana, from April 11 to July 1, the 1500- and 3000-pound residue levels caused an average lag in daily maximum soil temperature at the 2-inch soil depth of 4.0° and 9.2° F., respectively, as compared with the bare plot. (SWC 10-d5)

Detailed plant studies made on wheat at North Platte, Nebraska, at various plant growth stages from seedling to maturity revealed that the number of heads per square foot and the grain produced per acre were less when the residue was left on the surface as compared with fall incorporation. In these studies, the application of N fertilizer increased the N content of the plant material and the number of heads per square foot, but did not increase grain production. These data suggest that the factor, or factors, limiting grain production on land with plant residues still is unknown. (SWC 10-d5)

5. Cropping systems. Two 6-year crop sequences designed to determine the benefits of a green manure crop as compared with application of nitrogen fertilizer were studied at Pullman, Washington. The 6-year averages indicate that winter wheat following peas yielded 57 bushels per acre, and winter wheat following wheat yielded 53 bushels per acre where 100 pounds of nitrogen per acre was applied. Where 50 pounds of nitrogen per acre were applied, the yields of wheat in the same two crop sequences were 53 and 45 bushels per acre, respectively. Winter wheat yield following alfalfa-grass as a green manure crop has averaged 49 bushels per acre during the same study period. (SWC 10-f2)

Leaf area index studies at Blacksburg, Virginia, were continued with Kentucky 16 and Mammoth Burley tobacco at plant population densities ranging from 3,920 to 15,682 plants per acre under two soil moisture regimes. Leaf area index values as high as 8.8 were obtained by midseason; however, at these high levels, 20 to 30 percent of the leaves were lost from the lower part of the stalk by harvest time, even under the most favorable soil moisture levels. The data indicate that the conventional 18 x 42-inch spacing used for the Mammoth Burley, as well as for Kentucky 16, gives the highest yields. (SWC 10-a1)

A Coastal bermudagrass-fescue cropping system appears to have merit for year-round land and climate utilization in Georgia. However, clipping height and nitrogen level must be rigorously managed. Annual yield increases due to fescue were not large, but the growing season was extended from 3 to 4 weeks, both in the spring and the fall, resulting in a more even distribution of dry matter production in pastures. Seeding rye for grain in Coastal bermudagrass sod is practical and profitable in years of normal rainfall. Thirty-eight bushels of grain were obtained with a loss of about one ton of forage. Harvesting the small grain earlier for hay or silage appears even more promising. (SWC 10-b4)

6. Nutrient requirements for various crops. In a wheat-fallow system of farming near Pendleton, Oregon, Gaines winter wheat continues to yield about 22 percent more than the Omar and Brevor varieties. Yields were highest with a late September or early October seeding date for all three varieties. The efficiency of use of stored soil moisture (bushels per acre per inches soil water used) was influenced by variety, seeding date, and N fertilization. For Gaines, the moisture-use efficiency was 5.8, 7.8, and 6.2 for the September 1, October 1, and November 1 seeding dates, respectively. (SWC 10-f1)

D. Soil Microbiology

1. Decomposition of residues. Plant residue mulches have been important in runoff and erosion control practices in many agricultural areas. However, the practices have not received widespread acceptance because crops planted in mulches frequently suffer from poor stands and reduced yields. Previous studies conducted at Lincoln, Nebraska, reported in 1963 and 1964, showed that patulin, a phytotoxic substance produced by the fungi, Penicillium urticae Bainier, is toxic to many crops. During the year, emphasis was placed on improvements in extraction techniques. Using the new technique developed at Lincoln, it was possible to extract patulin from samples of Keith silt loam. An examination of the extract with two-dimensional chromatography revealed patulin present at 75 p.p.m. in the straw and 1.5 p.p.m. in the soil. These data are significant in that it is now possible to quantitatively measure patulin in an unsterilized natural soil. (SWC 10-d5)

Also at Lincoln, Nebraska, pot experiments have been conducted to determine whether exposure of wheat plants to low patulin levels over the growth cycle will affect the final yield. Results indicate that once the plant is definitely adversely affected (symptoms such as necrosis, narrowed and shortened leaves, leaf tip burning, unthriftiness, shortening of first internode, chlorosis, and germination reduction), it does not recover. These results suggest that the damage from patulin frequently observed in the seedling stage will be reflected in final yield. (SWC 10-d5)

Studies have been initiated at Florence, South Carolina, to evaluate the degree that water extracts of plant tops and roots are toxic to emerging and seedling plants. Ten field crops and ten weeds were included in the study. About one-third of the field crop extracts inhibited germination, but others stimulated germination and emergence. For example, corn extracts stimulated the emergence and germination of cotton, and Coastal bermudagrass tops stimulated but the roots inhibited the emergence of cotton. These results suggest that this area needs to be investigated further and that it may be possible from these data to develop better guides for designing cropping systems. (SWC 10-b5)

2. Inoculation of legumes. Results reported last year from Fort Collins, Colorado, indicated that large amounts of organic nitrogen accumulate in mountain meadow sods. In laboratory studies during this year, fixation under aerobic, photosynthetic conditions was meager, but under anaerobic, dark conditions, fixation amounted to 50 pounds of nitrogen per acre in 120 days. Counts of aerobic and anaerobic organisms add further evidence that the latter may be responsible for nitrogen fixation in wet mountain meadows. Measurements of oxygen concentrations in sods in the presence of light showed that an anaerobic condition exists only at or beneath the water table. Field studies are planned for the summer of 1966. (SWC 10-d2)

The "sick alfalfa" problem of concern to several states in the Northwest remains unsolved. New microbiological studies with the problem soil have been initiated at Prosser, Washington. First-year results show that when normal and affected soils are sterilized and then inoculated with effective Rhizobium, the inoculation is only about 50 percent as effective on the soils where sick alfalfa occurs as on the soil where normal alfalfa grows. These results indicate the possible presence of a nonbiological factor that is capable of decreasing the invasiveness and the effectiveness of the rhizobia in the affected soils. (SWC 10-f4)

In a continuing study at Beltsville, Maryland, results have shown that rhizobia inoculated onto soybean seed produced very few nodules on the roots in competition with strains already present in the soil. Procedures were devised to obtain direct measurements of the populations of the different Rhizobium strains in the soil and in the root rhizosphere in efforts to explain this effect. Preliminary data indicate that Rhizobium populations of several million per gram of soil develop on soybean root systems, whether the inoculum comes with the seed, from the soil, or both. Strains inoculated on the seed multiply to high levels in the rhizosphere, even though they do not produce many of the nodules. An exception was noted when inoculated seed was planted late in July, at which time a very high population developed from the seed inoculation, which greatly overshadowed the strains from the soil and accounted for a high percentage of the nodules. Although all strains tested as inoculum seemed to compete well with the indigenous strains for multiplication, they differed greatly in their competitive ability to induce nodules. (SWC 10-aB)

Antibiotics in soils have always been of interest to soil microbiologists because of their importance to microflora ecology. Previous studies at Beltsville have revealed that the tendency of kaolinitic soils to bind and retain antibiotics is less than that found in montmorillonitic soils. Detailed studies made this year showed that microflora of kaolinitic soils had a higher level of resistance to antibiotics than did the microflora of montmorillonitic soils. This difference occurred because the large quantities of antibiotics in the soil solution of kaolinitic soils caused microflora to develop which would tolerate these substances. These data are of great interest because they furnish ecological evidence of antibiotic production in soils at levels too low for any available method of direct measurement. (SWC 10-aB3)

3. Soil fungi. The growth and behavior of fungi in soils have always baffled scientists. Previous studies have indicated that fungi in soils appear to be stimulated by plant residue without being in direct contact with it. In a study conducted at Beltsville, Maryland, dormant soil fungi were stimulated to active growth by the volatile materials given off by moist plant material. Because of the low concentrations involved, the plant material appears to act as a growth stimulator rather than as a source of energy. This exciting and potentially important phenomenon will be investigated in more detail. (SWC 10-aB)

In Poland, the study of the soil response to various rates of application of rye straw and alfalfa continues. Microscopic observation of thin section samples of soil aggregates from these various treatments revealed that amorphous organic matter is the aggregate binder. Considerable quantities of soil fungi were found to be part of the decomposition process. The fungi population varied directly with the clay content of the soil. (E21-SWC-2)

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AREA 11: SOIL, WATER, AND PLANT RELATIONS AS THEY AFFECT USE OF LAND AND WATER RESOURCES

Problem. Most of the water used in agriculture is returned to the atmosphere by the process of root absorption and leaf transpiration. Our understanding of the physical, physiological, and phenological aspects of the extraction of water from soil by roots, its translocation upward, and the manner in which water is lost from the leaves is limited. The productiveness of the soil depends to a large degree on how water moves within the soil. The mechanisms involved in the movement of water in the soil and to the plant root have not been adequately explained; consequently, the behavior of water in soil cannot be satisfactorily predicted. No basic understanding of naturally occurring field phenomena can be reached until our knowledge of water movement through soils and to plant roots is expanded.

The immediate climatic environment around the plant and at the soil surface, and the micrometeorological factors which affect these, have a profound influence on the growth of the plant, the loss of moisture from the soil and plant, and on the soil itself. These micrometeorological factors offer a means of conserving moisture during the course of plant development. It has been estimated that 80 percent of the sun's energy is used each year to evaporate some 2 million acre-feet of water from plants and soil. The total energy cannot be altered, but it should be possible to divert a greater percentage to use for photosynthesis rather than for evaporation.

USDA AND COOPERATIVE PROGRAM

The Division program in this area involves soil physicists, soil chemists, plant physiologists, and engineers in both basic and applied studies. The Division scientific effort devoted to this research totals 20.3 professional man-years. Of this number, 10 are devoted to soil physical properties as related to movement of air and water into plant roots; 6.3 to determination of plant-soil-meteorological interactions; and 4 to development of soil and crop management factors for maximum energy conversion.

PROGRAM OF STATE EXPERIMENT STATIONS

A total of 48 scientific man-years is devoted to this research.

PROGRESS -- USDA AND COOPERATIVE PROGRAMS

A. Soil Physical Properties as Related to the Movement of Air and Water Into Plant Roots

1. Adsorbed ions. The physical and chemical properties of the soil depend to a large degree on the movement and adsorption of ions in the soil-water system. Basic studies at Fort Collins, Colorado, conducted to evaluate the relative importance of naturally occurring soil constituents in the bonding of soil into aggregates and hard layers, indicate that the average mobility of adsorbed calcium is low because most of this calcium is on the internal surfaces of clay platelets. Data obtained from these studies furnish an explanation of the instability of clay and soil aggregates that have a high content of exchangeable adsorbed sodium. (SWC 11-d1)

In another study at Fort Collins, the energies with which cations adsorb water molecules were calculated by a technique which was corrected to take into consideration the hydration energy of the different ions. This corrected theory predicts, for the first time, the observed differences in the adsorption characteristics of the lithium, sodium, and potassium ions. Experimental observations were in general agreement with the theoretical predictions. (SWC 11-d1)

2. Thermal gradients. A basic description of the physical and chemical processes involved in the removal of moisture from the soil reservoir has not yet been developed. At Davis, California, laboratory studies on drying of a loam soil column under controlled diurnal thermal gradients suggested that isothermal physics is not sufficient to explain water movement under field conditions. It was shown that evaporation rate was dependent on the diurnal thermal wave and the ambient pressure in addition to the energy input to the system. Significant amounts of water are induced to move up or down in the soil profile, depending on the direction and magnitude of the thermal gradients. As the soil surface warms, there is a spontaneous diffusion of water down into the profile; as the soil surface cools, there is a diffusion of water upwards toward the surface. Under conditions in which the soil was dry on the surface and the daily evaporation rates were 1 or 2 mm. of water, the diurnal thermal wave caused several tenths of a millimeter of water a day to diffuse downward and lesser amounts to diffuse upward at night. These studies showed that the evaporation of soil moisture from a bare soil is essentially a heat-flow problem and solutions to the problem must include the interrelations between the transport of latent heat by water vapor. This type of experimental data is required before the solution to some of our existing field water problems can be developed. (SWC 11-13(g1)

Measurements of the soil-water diffusivity as a function of temperature were made by the outflow method at Riverside, California. The results did not show as large an effect as was obtained previously by the constant-flux method, but the effect was still larger than could be accounted

for by the change in viscosity to be expected for normal bulk water. In one case, the increase in diffusivity was 1.84 times too large and in the other 1.14 times over a fairly wide range of water contents. No theoretical explanation for this has been advanced as yet, since apparent activation energies calculated from these data give unreasonably high values. This suggests that the activation energy itself is energy dependent and that the adsorbed water is more highly structured than bulk water. As the temperature is increased, this structure might well tend to break down. Inasmuch as the suction decreases and the diffusivity increases with increasing temperature, an increase in soil temperature should be reflected in a slight increase in available water. (SWC 11-gF1)

The most common theory of the cause of moisture hysteresis is that the hourglass-shaped pore may be filled or emptied, depending on the tension and the minimum radius of the pore's inlet and outlet. The pore is envisioned to have bubbles of entrapped air. The relation between entrapped air and soil moisture hysteresis phenomena was studied at Davis, California. Measurements of entrapped air in three soils of different textural classes indicated a tendency for more air entrapment during the desorption cycle than during the absorption cycle, particularly at the higher moisture contents. These changes in entrapped air are opposite to those predicted by the commonly proposed hourglass soil moisture hysteresis theory. Consequently, a more realistic mechanism must be derived before we can expect significant advances in mathematical description of hysteresis and, consequently, of unsaturated soil moisture flow. (SWC 11-13(g1)

3. Vertical infiltration. Most investigations have been conducted on soil water flow using samples that are initially at a uniform water content. In a study at Urbana, Illinois, each level of soil in a verticle column was wetted at a different tension to obtain conditions similar to actual field wetting and drying of soils. By using this technique, the problem of vertical infiltration into a soil column initially at equilibrium with a water table has been solved numerically for ponded and rainfall infiltration into both uniform and stratified soil columns. These solutions take into account hysteresis in the water content-pressure head and hydraulic conductivity-pressure head relationships. However, using experimentally determined diffusivities in the numerical solution of the horizontal infiltration equation did not predict the observed water uptake pattern. The difficulty appears to be the inability to get good diffusivity values at high water contents. The results are among the first to take hysteresis into account, and they show that for some soils, usually those of heavier textures, the role of hysteresis is important, but that for others, it is not too important. (SWC 11-c3)

Also at Urbana, a computer program has been written to solve the steady-state, vertical-flow equation with a source term. This physically represents a column of soil in which plants are growing and taking up water. Several different formulations for the source term are being tested. (SWC 11-c3)

4. Neutron transport in a soil-water system. The use of neutron-scattering apparatus for measuring the soil-moisture content has been accepted as a standard method. This has resulted in a large number of probes being used without questioning of the theory used to develop the instrument. At Brawley, California, experiments were conducted this year to determine if the Flugge solution to the distribution of thermal neutrons about a point source of fast neutrons in water is applicable to a soil-water system. Distribution of thermal neutrons from a 1-curie plutonium-Beryllium source of fast neutrons was measured in a 4-ft.-diameter by 4-ft.-high barrel as a function of soil-water content. Fermi "age" and transport mean free path were logarithmically related to soil-water content. Results indicated that the mathematical solution developed by Flugge satisfactorily predicted the distribution of thermal neutrons in the soil-water system. The distribution of neutrons was sperically symmetrical about the source, although the volume of soil around the source was too small to avoid neutron leakage, and at low moisture contents, the usual distribution of thermal neutrons was somewhat distorted. (SWC 11-13(g1))

5. Stage of plant growth and moisture stress. The importance of supplying adequate moisture to plants at certain periods, such as tasseling to silking with corn, has been defined for several crops. Studies at Weslaco, Texas, conducted over a period of 5 years, showed that cotton yields are determined by moisture supply during the blooming and fruiting period of plant development. Rainfall during this moisture-critical period of plant development can entirely eliminate influence of seasonal moisture treatment on yield. These data are of great value in developing irrigation systems for cotton in water-deficient areas. (SWC 11-e1)

It is frequently possible to estimate visually whether a crop in the field needs water by the appearance of grayish or bluish plant color. To evaluate the possibility of estimating water status spectrophotometrically, and to provide information to be used in remote-sensing studies of plants, an investigation of the spectral qualities of leaves was undertaken at Urbana, Illinois. Reflectance studies with cotton confirmed the observation that most leaves reflect more visible light from their backs than from their faces. Between wavelengths of 750 and 1350 mμ, the backs of leaves reflect less light than do the faces. Data indicate that in the 750- to 1350-mμ band, 85 to 90 percent of the radiation was either reflected or transmitted. The shape of the reflectance curve at wavelengths greater than 1350 mμ was largely governed by the water in the leaf. These studies have helped to explain some of the differences found in infrared aerial photographs. (SWC 11-c1)

6. Soil aeration. Excessive CO_2 in soils, especially in conjunction with deficient O_2, is often cited as contributing to poor vegetative growth or germination of crops due to its toxic effects on various plant processes. Results of experiments with corn and soybean seedlings at Fort Collins, Colorado, indicate that the kind and extent of response obtained from a

given CO_2 treatment was influenced in varying degrees by time, soil suction, plant species, and the growth variables measured. The importance of excessive CO_2 as a causal agent of plant injury during germination has probably been overestimated. Corn and soybeans during germination tolerated, and sometimes were stimulated by, CO_2 concentrations higher than those normally found in soils. When CO_2 was sufficiently high to cause severe toxicity, seedlings recovered quickly upon aeration. (SWC 11-d1)

The heavy clay soils that make up the Texas Blacklands are quite unproductive. One of the factors contributing to this low productivity is the low gaseous diffusion rates in the soil. At Temple, Texas, studies initiated in 1964 to evaluate root development at various soil CO_2 and O_2 levels were continued in 1965. Oxygen contents measured in Houston Black clay varied greatly with location, indicating the presence of both well and poorly aerated zones in close proximity to each other. Variation in gas composition in the undisturbed soil was due to soil structural conditions. Even though roots penetrated deeply in a few places, they bypassed a large percentage of the soil. Tilling the soil to 2 or 4 feet resulted in much more uniformity in spatial gas composition to the tillage depth. (SWC 11-e1)

Procedures were developed at Brawley, California, to determine the effect of moisture content, temperature, and length of irrigation on the redox potential and oxygen diffusion rate in soils. By using selected black platinum micro-electrodes in the field, it was found that increasing temperature and length of irrigation lowered the redox potential and oxygen diffusion rate in the soil under alfalfa plants. This technique provides a means of comparing field and laboratory conditions, which may be helpful in the interpretation and use of laboratory data. In the laboratory, redox potential measurements in incubated flasks showed that either reduced oxygen percentages in the aeration mixture or increased soil moisture content lowered the redox potential. These preliminary results clearly indicate that high temperatures and long irrigations result in poor aeration conditions. (SWC 10-g1)

Studies at Auburn and Thorsby, Alabama, indicate that oxygen concentration in the soil is a function of soil moisture, and that the relationship can be measured automatically with a system using membrane-covered platinum electrodes with battery-powered instrumentation. In the first year of a field experiment, irrigation sharply reduced the effectiveness of cotton in extracting subsoil moisture. This and a temporary reduction in O_2 content of soil air following irrigation suggest poor aeration as a root-restricting factor. Nitrogen fertilization considerably improved subsoil moisture extraction by the crop and also increased the top:root ratio, primarily through increased top growth. (SWC 10-b6)

B. Determination of Plant-Soil-Meteorological Interactions

1. Radiant energy absorption. An experiment, initiated in 1964 at Urbana, Illinois, to study the influence of light, water, and carbon dioxide on soybean production, was continued during 1965. The net and spectral radiation decreased exponentially with depth into the crop canopy, because soybeans tend to develop a dense layer of randomly oriented leaves near the top. Visible radiation had a higher extinction coefficient than did net radiation. The experimentally measured rates of apparent photosynthesis and the efficiencies of energy conversion in fully developed closed canopies of soybeans compared favorably with similar data reported for good canopies of corn. (SWC 11-c2)

2. Diurnal growth of plants. The growth habits of grain sorghum, a crop as important to the Great Plains as corn or soybeans is to the Corn Belt, have never been critically evaluated. The factors responsible for the diurnal variation in the growth rate of grain sorghum have been studied during the past year at Bushland, Texas. Continuous growth measurements made with an electronic growth sensor in a grain sorghum field showed that the maximum growth rate occurred in the afternoon, and the minimum rate occurred about 9:00 a.m. The data suggest that growth rate is proportional to solar radiation during the day and inversely proportional to air temperature at night. (SWC 11-e1).

3. Leaf temperature and soil moisture stress. Heat budgets and water balance models have been successfully used to predict evapotranspiration rates and energy depletion, but sophisticated equipment involving detailed measurements are required. An experiment initiated in 1963 at Weslaco, Texas, to evaluate the relationship between leaf temperature and relative turgidity of cotton leaves, has shown that a decrease in relative turgidity from 83 to 59 percent (corresponding to afternoon turgidities of recently irrigated and badly wilted plants, respectively) resulted in a 3.5-degree increase in leaf temperature. Data from these studies suggest that leaf temperature measurements can be used for predicting the crops' need for irrigation. (SWC 11-e1)

4. Stomatal activity. The evaluation of the influence of light intensity on leaf diffusion resistance has continued during the year at Phoenix, Arizona. Previous studies have shown that cyclic changes in stomatal aperture and concurrent changes in transpiration, leaf temperature, and leaf water content of cotton plants occur under carefully controlled growth chamber conditions. During the year, these studies were carried to the field. Leaf diffusion resistance was measured at 30-minute intervals on sorghum in three field lysimeters. These data were obtained during two contrasting periods, one wherein soil water content was depleted, followed in a few days by one with freely available soil water. In wet soils, leaf diffusion resistance values showed a typical diurnal cycle, with high values in the dark and low values in daylight. An

appreciable increase in daylight resistance values did not occur until almost all available soil water had been depleted. Of real interest was the observation that sorghum leaves did not suffer an appreciable loss ir turgor even when the stomates were only partially closed. One of the possible explanations to this observation is that sorghum extracts water at a fast enough rate to resist leaf dehydration, despite low availabilit of soil water, a capability that may be related to its drought tolerance A second possible explanation is that the guard cells are more sensitive to lowered turgidity than the other leaf cells. (SWC 11-gG1)

In the same experiment, transpiration was calculated from measurements of leaf temperature, ambient vapor pressure, leaf diffusion resistance, and boundary layer resistance. For cotton, sunflower, and lemon, calculated values were consistently higher than those of the standard obtained by weighing. However, progress in evaluating all parameters relevant to the transpiration process is demonstrated by achievement of only a 20-percent disparity between the calculated and measured values in two plant sunflower and lemon. It is believed that the leaf diffusion resistance measurements are responsible for the lack of better agreement. (SWC 11-g

In continuing studies at Watkinsville, Georgia, concerned with determini the effect of light and other factors on stomatal behavior, two sensitive lysimeter systems were developed for use in the studies during the year. Transpiration rates as high as 2 grams per minute were measured from a mature cotton plant with 167 leaves and a total leaf area of 1.1 m^2. Transpiration rates varied as much as 10 percent from one minute to the next in preliminary studies. (SWC 11-b2)

In a parallel study of the mechanism of guard cell action, it has been shown that oxygen is required for the light-activated opening movement o guard cells. In the absence of atmospheric oxygen, this requirement may be met by the production of oxygen in photosynthesis. Under conditions low oxygen, the chloroplasts of guard cells were much reduced, indicatin limited chloroplastic activity. A preparation showing starch degrading and, possibly, synthesizing ability was isolated from epidermal and guar cell material. Stomatal activity appears to be very definitely associat with changes in cellular permeability. (SWC 11-b2)

Experiments at Ithaca, New York, involved with an evaluation of the fact that control transpiration and photosynthesis under field conditions continued. Two related studies were made of transpiration and transpira resistance as a function of leaf-water and stomatal characteristics in field crop communities. Results showed that corn, in comparison with su flowers, has a much higher threshold leaf-water content at which stomate close, thereby conserving water and preventing leaf turgor loss. Soybea are evidently intermediate. These findings are very significant because they bring us much closer to answering basic questions on drought tolerance and water-use efficiency. (SWC 11-a1)

Also at Ithaca, New York, two methods for evaluating the turbulent diffusivity coefficient in plant communities were compared. The two methods agreed well at the top of the canopy, but disagreed somewhat at the bottom of the canopy. It was concluded that the energy balance method is better under conditions of low windspeed, but that the momentum balance method gives more reliable results at high windspeeds. (SWC 11-a1)

C. Development of Soil and Crop Management Factors for Maximum Energy Conversion

1. Influence of barriers on microclimate. Attempts in the field to alter the microclimate in soybeans by the use of single-row plant or artificial barriers continued at Morris, Minnesota, this year. For the third straight year, plant height, dry matter weight, and grain yield of soybeans were increased in areas sheltered by a windbreak composed of double corn rows. The increased soybean yields in the areas protected by the barriers were sufficient to offset the increased costs of the system. (SWC 11-c2)

2. Influence of variety on microclimate. In an attempt to manipulate the microclimate in a cotton crop, okra-leafed plants were compared to normal plants. Results showed that the okra-leafed cotton matured before the insect population pressures became severe, but the photosynthetic efficiency and yield of the okra-leafed and normal cotton were the same. (SWC 11-b1)

In the same experiment, the crop surface temperature of irrigated corn exceeded that of irrigated cotton by 2^{o} or 3^{o} C. Transpiration measurements showed that cotton may dissipate twice as much energy as latent heat as does corn. The studies showed that air temperature in the range of 18^{o} to 36^{o} C. had little or no effect on rates of net photosynthesis. Under conditions of low moisture stress, a curvilinear relationship between water consumed and carbon fixed exists in both corn and cotton. Slopes of these curves increased with increasing photosynthetic rate, and the slopes were greater for cotton than for corn. (SWC 11-b1)

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AREA 12: NUTRITION OF ANIMALS AS AFFECTED BY PROPERTIES AND CHARACTERISTICS OF SOILS AND PLANTS

Problem. To improve nutrition of animals and man by discovering relationships among soils, plants, and animals; to develop basic understanding of the synthesis and metabolism of nutritionally important substances in plants and animals; to determine the functions and pathways of transport of the various elements throughout the food chain from soil to plant to animal; to identify and characterize soil and climatic areas where the nutritional status of animals and man is affected adversely by qualities of the plants produced; to determine the relationships among soil properties, both natural and as modified by treatment and climatic factors, and the nutritional quality of plants as measured chemically or by feeding test animals so as to enable farmers to select economic combinations of soil, crop, and livestock management practices that will meet human nutrition needs.

USDA AND COOPERATIVE PROGRAM

This research is centered at the U. S. Plant, Soil, and Nutrition Laboratory a U.S.D.A. Laboratory located on the campus of Cornell University. Problems in animal nutrition that are prevalent in specific regions are investigated through field surveys in which the incidence of the nutritional problem is related to the composition of forages, types of soil and other environmental factors. Recent work includes studies of the relationship of selenium in forages to the incidence of muscular dystrophy in livestock. The chemistry of micronutrients in soils is under intensive study in order to develop basic knowledge of factors that influence the micronutrient content of plants. Other investigations are directed toward understanding the functioning of micronutrients in the animal, and the mechanisms involved in the interactions between micronutrients in animal nutrition. Studies of the site and mechanism of absorption of trace elements in the gastrointestinal tract are underway. The processes involved in the synthesis and breakdown of nutritionally important compounds in plants and animals are under investigation. One phase of these studies is directed toward the mechanism of formation and metabolism of amino acids and related compounds in plants, with special attention being directed toward the sulfur-containing amino acids. Another phase of this work is concerned with protein, and the relationship between molecular structure and the biological function of some of the compounds that play important roles in protein synthesis.

Studies involving large animals are conducted through cooperation with State Agricultural Experiment Stations. An investigation of the effect of soil applications of selenium upon the incidence of myopathy in sheep

is being conducted at Oregon State University. Studies of plant composition in relation to the occurrence of "grass tetany" in cattle are underway, in cooperation with the State Experiment Stations in Georgia and Nevada.

The research team that discovered the first structure of a ribonucleic acid received the Distinguished Service Award of the U. S. Department of Agriculture during the past year, and the former leader of the team, Dr. R. W. Holley, now Professor of Biochemistry at Cornell University, received the Albert Lasker Award for research in biology and medicine.

The Federal scientific effort devoted to research in this area totals 14.5 professional man-years. Of this number, 3 are working to characterize soil and climatic areas where the nutritional status of animals and man is affected adversely by quality of plants produced; 2.5 are devoted to basic understanding of the metabolism of nutritionally important elements in animals; 3 to assays of plant material grown under different soil, geological, and other environmental conditions in relation to nutritional disorders in animals and man; and 6 to elaboration by plants of vitamins, amino acids, proteins, and other organic nutrient compounds required by animals. The Soil Conservation Service maintains a full-time scientist at the Plant, Soil, and Nutrition Laboratory for studies relating nutritional problems to specific kinds of soil.

PROGRAM OF STATE EXPERIMENT STATIONS

A total of 17* scientific man-years is devoted to this research.

PROGRESS -- USDA AND COOPERATIVE PROGRAMS

A. Biosynthesis of Amino Acids, Peptides, and Proteins

1. The structure of transfer ribonucleic acids. The structure and function of the transfer ribonucleic acids (RNA's) have been investigated at the U. S. Plant, Soil, and Nutrition Laboratory for the past 8 years. These studies are important to biology and nutrition because the transfer RNA's play an important role in protein synthesis. The determination of the first known structure of a ribonucleic acid was reported in 1964. (SWC 12-aA4)

During the past year, the structure of a second transfer RNA has been determined. This second RNA is one that transfers the amino acid, tyrosine, to the site of protein synthesis in living cells. This problem of structure was essentially one of determining the sequence of units called nucleotides in a long-chain molecule. The long-chain molecule was broken into fragments by treatment with enzymes, and the nucleotides in the fragments were identified. (SWC 12-aA4)

* Also reported in Animal Husbandry.

Word has also been received that a laboratory in Germany has very recently succeeded in determining the structure of still another transfer RNA, using a research approach similar to the one developed at the U. S. Plant, Soil, and Nutrition Laboratory. Thus, in the 15 months since the first structure of an RNA was established at Ithaca, two more RNA's can be added to the "known" list. (SWC 12-aA4)

These advances now set the stage for attack upon the relation of RNA structure to RNA function and for moves toward understanding the mechanisms whereby RNA's carry out the genetic instructions within the living cell. (SWC 12-aA4)

2. Nitrogen and sulfur compounds of plants. The nutritional quality of plant proteins is often lower than that of animal proteins, because of a relative deficiency of sulfur-amino acids and lysine. With this fact in mind, studies are continuing on the synthesis of sulfur-amino acids in plants. Last year, the finding of an enzyme that degrades the sulfur-amino acid, cysteine, was reported. Since then, this enzyme has been partially purified and characterized. The characterization resulted in the observation that the degradative enzyme can be inhibited by thiols. This observation makes it possible to study cysteine synthesis in plant systems, even in the presence of the active degradative enzyme which was interfering with previous work on cysteine formation. (SWC 12-aA7)

In studies of the synthesis of the sulfur-amino acid, S-methylcysteine, it was found that this amino acid can be formed by reduction of S-methylcysteine sulfoxide, which is found in many plants. The S-amino acid, methionine, may be formed in a similar manner from methionine sulfoxide. (SWC 12-aA7)

Experiments with radioactive S-methylcysteine have demonstrated a transfer of its methyl group to methionine. This discovery is significant because it indicates the possible importance of methylcysteine in transmethylation processes and methionine biosynthesis in particular. Whether methylcysteine is an obligatory precursor of methionine or an alternative one remains to be seen. (SWC 12-aA7)

Several years ago, it was observed that the amount of amino acids changed markedly during incubation of wilted leaves. Proline was the only amino acid that increased with wilting. This observation raised the question of what controls proline biosynthesis and degradation, and emphasized our lack of knowledge concerning these processes in plants. Detailed study of some possible mechanisms of proline formation indicates that this amino acid is formed from glutamic acid with glutamic semialdehyde as an intermediate. In the metabolism of proline in plants, the proline appears to be converted back to glutamic acid through the same intermediate, but by different enzymes. If this is so, it could be assumed that the accumulation of proline by the wilted leaf provides a mechanism for storing nitrogen,

hydrogen and carbon in a highly available form. Studies of the proline synthesis in wilted leaves have revealed that sugar is necessary. However, the mechanism that triggers increased proline synthesis in wilting plants has not yet been found. (SWC 12-aA7)

B. Trace Element Functions and Interactions in Animal Nutrition

1. The role of manganese in bone formation. Research has continued on the role of manganese in bone cartilage formation. Previous results have demonstrated that manganese deficiency caused a severe reduction in the galactosamine mucopolysaccharides of these tissues. These polysaccharides form the organic matrix that is later calcified to form bone. No evidence could be obtained that the decrease in mucopolysaccharide content was due to increased hydrolytic decomposition of the mucopolysaccharides by lysosomal enzymes. (SWC 12-aA8)

In view of the above findings, attention has been directed to the synthetic aspects of hexosamine metabolism. For this purpose, an *in vitro* system was developed with which hexosamine synthesis by tissue homogenate could be studied. (SWC 12-aA8)

Homogenates of epiphyseal cartilage of chicks receiving deficient or adequate amounts of manganese synthesized similar amounts of hexosamine. Glucosamine was the primary hexosamine synthesized, with only small amounts being converted to galactosamine. Although only relatively small amounts of galactosamine were formed, tissue from chicks receiving adequate amounts of manganese consistently formed more galactosamine than did tissues from manganese-deficient chicks. Addition of manganese to the *in vitro* synthetic system did not increase the synthesis of galactosamine. (SWC 12-aA8)

Since these experiments indicated that manganese deficiency does not lead to an impairment of hexosamine synthesis per se, the conversion of glucosamine to galactosamine was the next reaction to be studied. The enzyme responsible for this conversion is called UD P-N-acetyl-glucosamine-4-epimerase. As with the other enzymes involved in hexosamine synthesis, the epimerase activity is found in the supernatant obtained from centrifuging homogenates at 105,000 X G. One of the problems of assaying this enzyme is that at equilibrium, there is only 30 percent conversion of glucosamine to galactosamine. In order to remove the free galactosamine formed, the microsomal fraction was added to the assay medium. This fraction contains the enzymes used to polymerize the individual components into mucoproteins and mucopolysaccharides. (SWC 12-aA8)

Using the above assay procedures, it has been found that liver and epiphyseal cartilage tissues from manganese-deficient chicks contain less epimerase activity than do comparable tissues from normal chicks. These findings support the hypothesis that manganese is required for the

conversion of glucosamine to galactosamine. This research program is being continued in an attempt to define the role of manganese in this enzymatic epimerization. (SWC 12-aA8)

2. Nutritional interrelationships of zinc and copper. Investigation of the mechanism by which zinc interferes with copper utilization has been continued. Some of the earlier studies indicated that when rats were fed a copper-deficient diet, as little as 50 p.p.m. of added zinc would further depress weight gains and hemoglobin levels. In studies to determine the site of copper utilization and stage in the process at which zinc impeded copper utilization, labeled copper and unlabeled zinc were administered to animals in various combinations of intraintestinal and intraperitoneal inoculations. Preliminary data indicate that high levels of zinc interfere with the passage of copper-64 across the gut wall and also affect the distribution of the absorbed copper-64 among the tissues. (SWC 12-aA3c)

Early attempts to produce copper-deficient rats showed that preweaning nutrition of the young rats was very important. Experiments were then undertaken to determine a dietary level of copper that would allow female rats to deliver their litter and rear them to weaning age, yet produce weanling rats that were susceptible to copper deficiency. Littermate females were assigned to diets containing 0.5, 2.0, 4.0, or 6.0 p.p.m. of copper. Preliminary data indicate that 0.5 p.p.m. of copper is not adequate for production of weanling rats. The susceptibility of the offspring to copper deficiency was tested by feeding half of the males from each litter a copper-deficient diet and feeding the other half a copper-adequate diet. The rats from mothers on diets containing 2.0 p.p.m. of copper were the first to show copper-deficiency symptoms; the ones from mothers on 4.0 p.p.m. were second; and the rats from mothers receiving 6.0 p.p.m. were last to show copper-deficiency symptoms. It appears that 2.0 p.p.m. of copper in the diet of the mothers will permit adequate production of weanling rats, but these weanlings will develop copper deficiency after weaning unless a copper-adequate ration is used. (SWC 12-aA3c)

Efforts to elucidate mechanisms involved in the regulation of copper retention by the animal have been continued. Since the regulatory mechanisms should be most evident during times of stress, these efforts have been concentrated on either copper-deficient rats or on rats dosed with high levels of copper. In studies conducted this year, an attempt was made to determine if the increased isotope uptake from the intestine of copper-deficient rats represented an increase in the efficiency with which copper was absorbed. In these experiments, 25 percent of the dose disappeared from isolated intestinal segments of copper-adequate rats in 3 hours, compared with a 37-percent disappearance of copper-64 from similar segments in copper-deficient rats. However, the stable copper content of the segments was about 2.5 times higher in the copper-adequate than in the copper-deficient rats. Thus, a simple dilution effect could provide an explanation. (SWC 12-aA3c)

In other studies, copper-64 and varying doses of carrier copper were placed in isolated, in vivo, intestinal segments. At low doses, the copper was distributed in the intestine, but at high doses (100 to 800 µg. per rat) a high percentage of the copper disappeared from the segment. As the dose increased, the proportion of copper retained by the liver increased and the proportion in the blood and kidney decreased, suggesting that as other tissues become saturated, the copper is diverted to the liver. When the liver becomes saturated, movement of copper out of the intestine decreases. Further studies will be designed to test this hypothesis. (SWC 12-aA3c)

3. Nutritional interrelationships involving iron and copper. In previous studies at the U. S. Plant, Soil, and Nutrition Laboratory, it has been shown that the mechanism of molybdenum toxicity in animals on copper-deficient diets is different from the mechanism of molybdenum toxicity in animals receiving an adequate level of copper. This work has now been extended to include studies of iron-copper interrelationships in relation to the copper status of the animal. (SWC 12-aA3c)

In copper-depleted rats, there is a negative correlation between the amount of copper and the amount of iron in the liver, and addition of copper to the diet of a copper-depleted rat results in a decrease in the store of iron in the liver. In copper-adequate rats, there is no correlation between liver copper and liver iron, and additional dietary copper does not reduce the liver stores of iron. When molybdenum and sulfates are added to the diet of copper-deficient rats, the liver stores of iron are increased, and the symptoms of copper deficiency (or molybdenum toxicity) are accentuated. (SWC 12-aA3c)

4. The effect of manganese deficiency on the performance of rats. Although manganese deficiency in rats is known to produce ataxia and reduced resistance to electroconvulsive shock in the offspring, there is little information on the possible effects of manganese deficiency on the nervous system of the parental generation. In an effort to obtain some information on this point, rats raised on a manganese-deficient or a manganese-adequate diet were tested for their ability to perform in a simple maze situation. (SWC 12-aA3c)

The rats on a deficient diet learned the correct route to obtain food in fewer trials than the rats on the manganese-adequate diet. There was no significant difference between the groups when escape from water was the reward. Comparison of the performance of the manganese-deficient and manganese-adequate rats with that of rats raised by a supplier, presumably on a standard pellet diet, suggested that the performance of both the manganese-deficient and manganese-adequate rats in the water maze was inferior. These experiments raise the interesting possibility that an excess of manganese may be more detrimental to performance than a deficiency of manganese. (SWC 12-aA3c)

C. The Effect of Soils on the Nutritional Quality of Plants

1. Soil magnesium in relation to the occurrence of "grass tetany" in cattle. Grass tetany (hypomagnesaemia) has killed numerous cattle in some of the Western States and also in certain areas in the Southeast during recent years. This disease occurs in the spring when cattle are turned out on the new growth of cool-season grasses or winter grains. Injection of affected animals with magnesium, if done promptly, will usually prevent death and relieve symptoms of tetany. (SWC 12-aA2)

Studies to determine whether increases in the level of available magnesium in the soil will result in winter grain forage that will prevent the occurrence of grass tetany in cattle are underway at Tifton, Georgia. The results to date indicate that a decrease in blood magnesium occurs when rye forage produced on low-magnesium areas is fed to lactating cows, but this decrease in blood magnesium is not observed when cows are fed rye produced on magnesium-fertilized areas of similar soil. (SWC 12-aA2)

Recent work in California has indicated that trans-aconitic acid, a metabolic inhibitor, may be present in fairly high levels in some forage grasses coincident with occurrences of grass tetany in animals grazed on these grasses. This suggests the possibility that the trans-aconitic acid in grasses may be responsible for some derangement of the magnesium metabolism of the animal. This possibility is being tested in experiments conducted cooperatively by the U. S. Plant, Soil, and Nutrition Laboratory, the Animal Science Department of the University of Nevada, the Department of Soils and Plant Nutrition of the University of California at Davis, and the Southwest Branch of SWC. Trans-aconitic acid fed to heifers at the rate of 200 mg./day resulted in deaths of two out of six animals in prelinimary studies. No depression in the level of magnesium in the blood was observed, however, as a result of trans-aconitic acid feeding. (SWC 12-aA2)

Since grass tetany is often associated with cool, cloudy, spring weather, it is possible that the occurrence of high levels of trans-aconitic acid, or low levels of magnesium, or high ratios of potassium to magnesium may be related to growing temperatures. An experiment to check on this possibility is being conducted in plant growth chambers at Ithaca. (SWC 12-aA2)

2. Soil selenium and white muscle disease in lambs and calves. Recent research has established that the selenium compounds in alfalfa are an effective dietary source of selenium for the prevention of selenium-responsive diseases of animals. It has also been shown that under carefully controlled conditions, the addition of selenium to the soil will increase the selenium content of alfalfa to levels that protect lambs from white muscle disease (W.M.D.). Since excess selenium in plants can be toxic to animals, it is essential to know the chemical nature of the selenium remaining in the soil, and to be able to predict whether this

residual selenium may become available to the plants as time goes on. (SWC 12-aA2)

In a study of the behavior of selenium added to seven low-selenium soils, the addition of 2.5 p.p.m. of selenium (5 lbs.per acre) under greenhouse conditions resulted in alfalfa containing potentially toxic concentrations of selenium in four of the seven soils. As consecutive cuttings of alfalfa were taken, however, the selenium contents of the plants on six of the seven soils dropped to nearly constant protective, but subtoxic, levels. (SWC 12-aA2)

Laboratory studies showed that selenium is immobilized in soils by hydrous iron oxides and reduction of selenites to either selenides or to elemental selenium. Acid soil conditions favor the formation of the reduced forms of selenium. The factors influencing the reoxidation of this reduced selenium to forms that may be utilized by plants are not well understood. (SWC 12-aA2)

These experiments suggest that it may be possible to prepare a synthetic complex of iron oxide and selenium for use as soil additive. The use of this additive on low-selenium soils might insure for a long time the production of forages that would protect animals from W.M.D., and at the same time insure that the selenium remaining in the soil would not pose a toxicity hazard. (SWC 12-aA2)

If promising techniques for the use of selenium as a soil additive for the prevention of selenium-responsive diseases can be developed, it will be necessary to know the extent to which various plant species that might grow on selenium-treated areas take up this element. None of the plant species grown on a low-selenium soil treated with selenium at a rate (2 lbs. per acre) that might be used in practice took up appreciably more or less selenium than did alfalfa. (SWC 12-aA2)

Results of a study to determine the selenium compounds occurring in alfalfa indicate that as much as 60 percent of the selenium in the leaves is present as selenium-methionine incorporated into protein. Selenium-cystine, or its derivatives, has not been detected in the protein fraction. A peptide, soluble in 80 percent ethanol, also contains appreciable amounts of selenium. (SWC 12-aA2)

D. Mapping of Soil Areas that Produce Plants Containing Levels of Trace Elements that Result in Deficiencies or Toxicities in Animals

1. Selenium-deficient areas in the United States. Surveys of the selenium content of alfalfa and other forages in various parts of the United States, for the purpose of delineating broad areas where selenium-responsive diseases of livestock may occur, have been continued. This

work is conducted in cooperation with the Soil Conservation Service and the Snake River Conservation Research Center (SWC-ARS-USDA). As a result of these studies, it now appears that much of the Intermountain Basin area is characterized by a local pattern of variation in the selenium content of forages. This local pattern apparently is related to the kind and geologic age of the rocks which form soils on different parts of the landscape. (SWC 12-aA1)

2. Cobalt-deficient and molybdenum-toxic areas of the United States. Work on the preparation of a new map, showing the areas in the United States where forages are most apt to be deficient in cobalt or to contain toxic levels of molybdenum for grazing animals, has been continued. The results of an intensive sampling survey in Oregon are now being summarized, and samples collected in the Southwestern United States are being analyzed. (SWC 12-aA1)

E. Chemistry of the Micronutrients in Soils

1. Complexing as a factor in micronutrient availability to plants. Many acid soils are deficient in copper for optimum growth of plants, but zinc deficiency is fairly rare on such soils. On the other hand, calcareous soils are frequently deficient in zinc but rarely deficient in copper. Investigation of the complexing of copper and zinc in soil solutions of calcareous soils revealed that copper was complexed very strongly. The high degree of complexing of copper resulted in relatively high levels of total copper in the soil solution, even though the concentration of copper cations was as low as 0.01 p.p.b. or lower. Levels of zinc in the soil solution were, in all but one case, below 2 p.p.b. Complexing of copper in the soil solution may explain why copper deficiencies are very rare in calcareous soils, even though zinc deficiencies are very common. (SWC 12-aA5)

In an analog system simulating the mucilaginous layer around plant roots, the presence of fixed negative charges was compared with soluble agents in their potential contribution to the movement of zinc. The zinc was supplied as zinc sulfate, and the fixed negative charges were introduced into an agar-agar gel as carboxyl groups on polygalacturonic acid. The zinc was allowed to diffuse through the gel to a flowing system of water. Subsequently, calcium citrate was introduced into the water. Fixed charges introduced at the rate of 1 percent polygalacturonic acid increased zinc transport by 13 percent. Citrate in concentrations of 4×10^{-4} M increased transport 20-fold. It does not appear that immobile carboxyl groups, even in amounts higher than might be expected around roots, have a major role in the transport of microcations to roots. Soluble complexing agents such as citrate, on the other hand, play a potentially significant tole. A theoretical treatment allows for some generalization of the results to other cations and other complexing agents. (SWC 12-aA5)

Procedures were developed to separate some of the materials in soil solution responsible for complexing cations from other organic compounds present. It is hoped that these procedures will contribute to the characterization of the complexing agents. It has already been found that these organic ligands form 1:1 complexes with zinc and copper. This is important and helpful in the theoretical characterization of the behavior of complexing materials around roots. (SWC 12-aA5)

First steps have been taken to develop a mathematical model for the contribution of synthetic chelates and natural complexing agents to the nutrition of plants. From considerations of mass flow of water to the root and solute diffusion in reponse to a concentration gradient, it is possible to get a preliminary idea of how the complexing of metals may be expected to change as the surface of the plant root is approached. It is also possible through this means to direct attention to those characteristics of the soil environment that most seriously restrict our understanding of soil-plant-root relations. From this preliminary development, it is already apparent that complexing may either enhance ion uptake if the plant is accumulating the ion against a considerable concentration gradient or it may augment the plant's tendency to exclude ions that are not accumulated. (SWC 12-aA5)

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Work and Line Project Number	Work and Line Project Titles	Work Locations During Past Year	Summary of Progress (Yes-No)	Line Project Inc. in Area and Subheading
SWC 1	Sedimentation processes in relation to watershed development and protection.			
SWC 1-a1	Development and evaluation of means and measures for channel stabilization in the Northeast.	East Aurora, N.Y.	Yes	1-A-1, C-1, D-1, 2
*SWC 1-19(a2)(C)	Analysis and synthesis of bedload formulas.	University Park, Pa.	No	
SWC 1-b1	Sediment production, yield and delivery ratio in relation to climatic factors and watershed characteristics in the Southern Branch and at the U.S. Sedimentation Laboratory.	Oxford, Miss. Holly Springs, Miss. Cartersville, Ga. Watkinsville, Ga.	Yes	1-A-1, 2, 3, 4, 5
SWC 1-b2	Investigations of the nature and processes of reservoir sedimentation in the Southern Branch and at the U.S. Sedimentation Laboratory.	Oxford, Miss.	Yes	1-B, E
SWC 1-b3	Mechanics of sediment entrainment, transportation and deposition in natural and artificial channels in the Southern Branch and at the U.S. Sedimentation Laboratory.	Oxford, Miss.	Yes	1-C-2
SWC 1-b4	Investigations of stream channel morphology in the Southern Branch and at the U.S. Sedimentation Laboratory.	Oxford, Miss. Ft. Lauderdale, Fla. Watkinsville, Ga.	Yes	1-C-2, D-1, 3, F
SWC 1-b5	Development of structural measures for sediment control and for stream channel stabilization in the Southern Branch and at the U.S. Sedimentation Laboratory.	Oxford, Miss.	No	
SWC 1-7(c1)(R)	Sediment sources and yields in agricultural watershed in Corn Belt States.	Columbia, Mo. Council Bluffs, Iowa Coshocton, Ohio	Yes	1-A-2
SWC 1-17(c3)	Reservoir sedimentation studies in Corn Belt States.	Columbia, Mo.	No	
SWC 1-d2	Sediment production, yield and delivery ratio in relation to climatic, geologic, and watershed characteristics of the Northern Plains.	Hastings, Nebr. Rosemont, Nebr. Newell, S. Dak.	Yes	1-A-1
SWC 1-18(d3)	Factors influencing the stability and regime of channels in agricultural watersheds of the Northern Plains.	Hastings, Nebr. Ft. Collins, Colo.	Yes	1-B, D-1
SWC 1-e1	Sediment production, movement, and deposition in agricultural watersheds in the Southern Great Plains.	Chickasha, Okla. Riesel, Tex. Sonora, Tex.	Yes	1-A-1, 2, 4
SWC 1-e2	Stream channel stabilization and sediment control works in channels in the Southern Great Plains.	Chickasha, Okla. Stillwater, Okla.	Yes	1-D-1
SWC 1-f1	Sediment movement and deposition on upstream agricultural watersheds of the Pacific Northwest.	Boise, Idaho	No	
SWC 1-g1	Sediment yields of agricultural watersheds in the Southwest.	Tucson, Ariz. Tombstone, Ariz. Safford, Ariz. Albuquerque, N. Mex. Santa Rosa, N. Mex. Moorpark, Calif.	Yes	1-A-1, 2, 4, C-2
	*Approved March 30, 1966			

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Work and Line Project Number	Work and Line Project Titles	Work Locations During Past Year	Line Project Inc. in Summary of: Progress (Yes-No)	Area and Subheading
SWC 1-g2	Stream channel morphology and channel stability on agricultural watersheds in the Southwest.	Tucson, Ariz. Tombstone, Ariz. Safford, Ariz. Albuquerque, N. Mex. Lompoc, Calif. Moorpark, Calif.	Yes	1-D-1
SWC 1-g3	Nature and processes of reservoir sedimentation in the Southwest.	Tucson, Ariz. Tombstone, Ariz. Santa Rosa, N. Mex. Lompoc, Calif.	No	

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Work and Line Project Number	Work and Line Project Titles	Work Locations During Past Year	Line Project Inc. in Summary of: Progress (Yes-No)	Area and Subheading
SWC 2	Hydrology of agricultural watersheds and associated aquifers in relation to treatment for flood prevention and multiple use of water resources.	Beltsville, Maryland	Yes	2-H
SWC 2-a1	The relation of rain, snow, and frozen soils to the hydrology of agricultural watersheds in the Northeast.	Danville, Vt. Blacksburg, Va. Beltsville, Md.	Yes	2-A-1, 2, 5, 6, B-1
SWC 2-a2	Water yield in relation to climatic and watershed characteristics of land resource areas in the Northeast.	Danville, Vt. Blacksburg, Va. Beltsville, Md.	Yes	2-B-4, C-1, D-1, E-1
SWC 2-a3	Storm runoff and floodflows in relation to climatic and watershed characteristics of land resource areas in the Northeast.	Danville, Vt. Blacksburg, Va. Beltsville, Md.	No	
SWC 2-aD1	Analytical hydrography in watershed engineering.	Beltsville, Md.	Yes	2-A-1, B-1, F-1, 2, 3, G-1, 2, 3-A
SWC 2-b1	Relation of climatic and watershed factors to runoff rates and volume yields in the Southern Branch.	Ft. Lauderdale, Fla. Oxford, Miss.	Yes	2-B-4, D-1, E-1
SWC 2-b2	Precipitation characteristics influencing runoff from agricultural watersheds in the Southern Branch.	Ft. Lauderdale, Fla. Oxford, Miss.	Yes	2-A-1, 2, 3
SWC 2-b3	Runoff production by unit source area agricultural watersheds in the South.	Oxford, Miss. Holly Springs, Miss. Watkinsville, Ga.	Yes	2-B-3
SWC 2-b4	Subsurface and ground water accretion, depletion, movement and contribution to streamflow for agricultural watersheds in the Southern Branch.	Oxford, Miss. Ft. Lauderdale, Fla.	Yes	2-B-2, C-1, 2, D-2
SWC 2-c1	Precipitation and snowmelt characteristics influencing runoff from agricultural watersheds in Corn Belt States.	Coshocton, Ohio	Yes	2-A-1
SWC 2-c2	Runoff production by unit source area agricultural watersheds in Corn Belt States.	Coshocton, Ohio	Yes	2-B-1
SWC 2-c3	Relation of climatic and watershed factors to storm runoff in Corn Belt States.	Coshocton, Ohio Columbia, Mo. Council Bluffs, Iowa Fennimore, Wisc. Madison, Wisc.	Yes	2-F-1
SWC 2-c4	Relation of climatic and watershed physiographic and cultural factors to water yield in Corn Belt States.	Coshocton, Ohio Columbia, Mo. Council Bluffs, Iowa Fennimore, Wisc. Madison, Wisc.	Yes	2-E-2
SWC 2-c5	Aquifer and subsurface relationships in the hydrology of upstream agricultural watersheds in Corn Belt States.	Coshocton, Ohio Columbia, Mo. Fennimore, Wisc. Madison, Wisc.	Yes	2-C-2, D-1, E-3
SWC 2-27(c6)	Soil moisture regimes of agricultural watersheds in Corn Belt States.	Coshocton, Ohio Columbia, Mo. Council Bluffs, Iowa Madison, Wisc.	Yes	2-A-6, B-2
SWC 2-d1	Water yield as related to integrated climatic and watershed characteristics in the Northern Plains.	Hastings, Nebr. Rosemont, Nebr. Newell, S. Dak. Cottonwood, S. Dak. Akron, Colo.	Yes	2-B-3, E-2, 3

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Work and Line Project Number	Work and Line Project Titles	Work Locations During Past Year	Line Project Inc. in Summary of: Progress (Yes-No)	Area and Subheading
SWC 2-d2	Storm runoff and floods as related to integrated climatic and watershed characteristics in the Northern Plains.	Hastings, Nebr. Rosemont, Nebr. Newell, S. Dak. Cottonwood, S. Dak. Akron, Colo.	Yes	2-F-1
SWC 2-e1	Precipitation characteristics influencing runoff from agricultural watersheds in the Southern Plains.	Chickasha, Okla. Riesel, Tex. Sonora, Tex.	No	
SWC 2-e2	Runoff production by unit source areas in the Southern Plains.	Stillwater, Okla. Cherokee, Okla. Chickasha, Okla. Riesel, Tex. Sonora, Tex.	No	
SWC 2-e3	Relation of climatic and watershed factors to storm runoff in the Southern Plains.	Chickasha, Okla. Stillwater, Okla. Riesel, Tex. Sonora, Tex.	Yes	2-E-2
SWC 2-e4	Relation of climatic and watershed physiographic and cultural factors to water yield in the Southern Plains.	Chickasha, Okla. Stillwater, Okla. Riesel, Tex. Sonora, Tex.	Yes	2-C-2, D-2
SWC 2-f1	Aquifer-streamflow interrelationships in upstream agricultural watersheds of the Pacific Northwest.	Boise, Idaho	Yes	2-C-1
SWC 2-f2	Precipitation characteristics influencing hydrologic performance of agricultural watersheds in the Pacific Northwest.	Boise, Idaho Moscow, Idaho	Yes	2-A-1, 4
SWC 2-f3	Runoff and sediment movement on unit source watersheds of the Pacific Northwest as influenced by climate, soils, vegetation, and topography.	Boise, Idaho Moscow, Idaho	Yes	2-A-5, B-3, F-1
SWC 2-f4	Water accumulation, flood-wave movement and water yield from complex watersheds of the Pacific Northwest.	Boise, Idaho Moscow, Idaho	Yes	2-E-2
SWC 2-g1	Precipitation characteristics influencing the hydrology of agricultural watersheds in the Southwest.	Tucson, Ariz. Tombstone, Ariz. Safford, Ariz. Albuquerque, N. Mex. Santa Rosa, N. Mex. Lompoc, Calif. Tehachapi, Calif.	Yes	2-A-1, 4
SWC 2-g2	Relation of integrated climatic, watershed, and cultural factors to storm runoff from agricultural watersheds in the Southwest.	Tucson, Ariz. Tombstone, Ariz. Safford, Ariz. Albuquerque, N. Mex. Santa Rosa, N. Mex. Lompoc, Calif. Logan, Utah	Yes	2-D-2, F-3, G-2
SWC 2-g3	Relation of integrated climatic, watershed, and cultural factors to water yields from agricultural watersheds in the Southwest.	Tucson, Ariz. Tombstone, Ariz. Safford, Ariz. Albuquerque, N. Mex. Santa Rosa, N. Mex. Lompoc, Calif. Riverside, Calif. Logan, Utah	Yes	2-B-2, 3, C-2, D-2, E-2

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Work and Line Project Number	Work and Line Project Titles	Work Locations During Past Year	Line Project Summary of Progress (Yes-No)	Inc. in Area and Subheading
SWC 3	Hydraulics of irrigation, drainage and watershed protection and water supply structures, channels, and facilities.			
SWC 3-c1	Hydraulic design of structures for water use and control in the Corn Belt.	Minneapolis, Minn.	No	
SWC 3-e1	The hydraulics and measurement of channel, floodplain, and overland flow in the Southern Plains.	Stillwater, Okla. Chickasha, Okla. Tombstone, Ariz.	Yes	3-A, C
SWC 3-e2	Hydraulic design of structures for water use and control in the Southern Plains.	Stillwater, Okla. Chickasha, Okla.	Yes	3-B, 2-D-1
SWC 3-g1	The hydraulics of channel, floodplain and overland flows in the Southwest.	Tombstone, Ariz. Santa Rosa, N. Mex. Albuquerque, N. Mex. Logan, Utah	Yes	3-A

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Work & Line Project Number	Work and Line Project Titles	Work Locations During Past Year	Line Project Summary of Progress (Yes-No)	Incl. in Area and Subheading
SWC 4	Conservation of water supplies for agricultural use			
SWC 4-b1	Development of water supplies for irrigation in the South	Tifton, Ga.	Yes	4-B-1
SWC 4-14(b2)	The disposition of pesticides in soil and closely related water	Watkinsville, Ga. Baton Rouge, La.	Yes	4-D-1
SWC 4-c1	Improvement of water supply sources and storage facilities in the Corn Belt	Columbia, Mo.	Yes	4-B-1
SWC 4-3(d1), (Rev.)	Facilities, methods, and design criteria to pump, convey, control and measure water for agricultural purposes in the Northern Plains	Akron, Colo. Ft. Collins, Colo. Grand Junction, Colo. Gunnison, Colo. Mitchell, Nebr. Mandan, N. Dak. Newell, S. Dak. Cora, Wyo. Fontenelle, Wyo.	Yes	4-B-2
SWC 4-13(e2)	Facilities and procedures for conservation management of runoff water from agricultural lands in the Southern Plains	Bushland, Tex. Weslaco, Tex. Stillwater, Okla.	Yes	4-C-1, 2
SWC 4-g1	Control of water use by nonbeneficial plants and evaporation losses from storage and conveyance structures in the Southwest	Humboldt River Basin, Nev.	Yes	4-A-2, 3, D-2
SWC 4-g2	Recharge facilities, methods, principles and design criteria for storing water in underground reservoirs in the Southwest	Fresno, Calif.	Yes	4-C-1
SWC 4-g3	Control of agricultural water supply and conveyance seepage losses in the Southwest	Reno, Nev. Fallon, Nev. Yerington, Nev. Logan, Utah	Yes	4-A-1
SWC 4-gG1	Measurement, evaluation and control of seepage losses	Phoenix, Ariz.	Yes	4-A-1
SWC 4-gG2	Atmospheric and related boundary mechanisms in water vapor losses from plant, soil and water surfaces	Phoenix, Ariz.	Yes	4-A-2, 3
SWC 4-gG3	Measurement, evaluation and control of infiltration to conserve water	Phoenix, Ariz.	Yes	4-A-1, B-1
SWC 4-gG4	Physical processes in the soil affecting preventable losses of water by surface evaporation	Phoenix, Ariz.	Yes	4-A-2
SWC 4-gG5	Water measurement and control for water conservation	Phoenix, Ariz.	Yes	4-B-2
AIO-SWC-20	Biology and consumptive water use of perennial range plants under desert conditions	Jerusalem, Israel	No	
AIO-SWC-25	Removal of suspended matter and turbidity from water by flocculation with polyelectrolyte coagulants and coagulation acids	Haifa, Israel	Yes	4-C-2
AIO-SWC-36	Runoff inducement in arid lands	Rehovot, Israel	Yes	4-B-1

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Work & Line Project Number	Work and Line Project Titles	Work Locations During Past Year	Line Project Incl. in Summary of: Progress (Yes-No)	Area & Subheading
SWC 5	Irrigation principles, requirements, practices, and facilities for efficient use of water on farms			
SWC 5-a1	Irrigation practices and factors affecting the water requirement of crops in different land resource areas of the Northeast	New Brunswick, N. J. Blacksburg, Va. Norfolk, Va.	Yes	5-A-2, 3
SWC 5-b1	Irrigation requirements, practices and methods of application for efficient production of crops in the Southeast	Thorsby, Ala. Ft. Lauderdale, Fla. Watkinsville, Ga. St. College, Miss. Florence, S. Car.	Yes	5-A-1, 2, 3, B-2, 3
SWC 5-c1	Improvement in performance and design of irrigation systems in the Corn Belt		No	
SWC 5-d1	Irrigation practices, requirements and design criteria for efficient use of water and sustained crop production in the Northern Plains	Akron, Colo. Ft. Collins, Colo. Grand Junction, Colo. Gunnison, Colo. Lincoln, Nebr. Mandan, N. Dak. Newell, S. Dak. Fontenelle, Wyo.	Yes	5-C-2
SWC 5-5(e1)	Irrigation water management for efficient water use in the Southern Plains	Bushland, Tex. Weslaco, Tex.	Yes	5-A-1, 2, B-1
SWC 5-f1	Irrigation requirements, principles, and practices for efficient use of water in the Pacific Northwest	Twin Falls, Ida. Ontario, Ore. Prosser, Wash.	Yes	4-D-1, 5-A-1, 2, 3, B-1
SWC 5-f2	Surface and sprinkler design and operation principles and facilities for efficient water use in the Pacific Northwest	Boise, Ida. Twin Falls, Ida. Reno, Nev.	Yes	5-A-1, 2, B-1, 2, C-1, 2
SWC 5-8(g1) (R)	Improved irrigation water application systems for the Southwest	Riverside, Calif. Reno, Nev. Escalante Valley, Utah Logan, Utah Milford, Utah	Yes	5-B-1, 3, C-1
SWC 5-9(g2) (R)	Irrigation requirements of forage and cultivated crops in the Southwest	Phoenix, Ariz. Reno, Nev. Logan, Utah	Yes	5-A-1, 2
AlO-SWC-5	Performance and scientific design of sprinklers used for irrigation	Haifa, Israel	Yes	5-B-2
AlO-SWC-11	Further studies on the Blaney and Criddle formula V=KF to ascertain the consumptive use of water by plants by means of analysis of climatological data	Rehovot, Israel	No	
AlO-SWC-19	Crop, soil and water use effects of low intensity sprinkler irrigation application	Rehovot, Israel	Yes	5-B-2
AlO-SWC-29	Studies of the influence of plant and environmental factors on photo-synthesis, stomatal aperture and transpiration	Rehovot, Israel	Yes	5-A-2

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Work & Line Project Number	Work and Line Project Titles	Work Locations During Past Year	Line Project Incl. in Summary of: Progress (Yes-No)	Area and Subheading
SWC 6	Drainage principles, requirements, practices, and facilities for protection of crops and soils			
SWC 6-a1	Development and evaluation of surface and subsurface drainage practices in different land resource areas of the Northeast	Blacksburg, Va. Norfolk, Va. Burlington, Vt.	Yes	6-A-1, C, D-1, 3
SWC 6-b1	Drainage requirements of crops in the South	Ft. Lauderdale, Fla. Baton Rouge, La. Raleigh, N. Car. Florence, S. Car.	Yes	5-A-1, 6-D-1, 3
SWC 6-b2	Design, installation, and maintenance of surface and subsurface drainage systems with or without land forming and conditioning in the South	Fleming, Ga. Baton Rouge, La.	Yes	5-A-2, 6-A-2, D-2
SWC 6-c1	Improvement and modernization of surface and subsurface drainage practices and facilities in the Corn Belt	Columbus, Ohio Morris, Minn.	Yes	6-B-1, 2, D-2
SWC 6-d1	Drainage facilities, methods, and design criteria for protection and improvement of agricultural crops and soils in the Northern Plains	Ft. Collins, Colo. Grand Junction, Colo. Grand Forks, N. Dak.	Yes	6-B-1, C
SWC 6-12(e3)	Improved drainage systems design, materials, installation techniques and drainage requirements of crops in the Southern Plains	Weslaco, Tex.	Yes	6-D-1
SWC 6-g1	Basic drainage principles in the Southwest	Logan, Utah	No	
SWC 6-g2	Drainage facilities, methods and evaluation for irrigated lands in the Southwest	Brawley, Calif. Reno, Nev. Logan, Utah	Yes	6-B-1, 3
SWC 6-g3	Drainage and aeration requirements of crops on irrigated lands in the Southwest		No	
SWC 6-gF1	Principles of drainage as related to salt-affected soils	Riverside, Calif.	No	

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Work & Line Project Number	Work and Line Project Titles	Work Locations During Past Year	Line Project Incl. in Summary of Progress (Yes-No)	Area and Subheading
SWC 7	Saline, sodic, and related soils problems, and quality of irrigation waters and their relation to plant growth processes			
SWC 7-a1	Investigations of the effects of using saline and industrial waste waters on the yield and quality of plants, and on physical and chemical characteristics of soils	Norfolk, Va.	Yes	7-B-2, E
SWC 7-b1	The effect of brackish water on plants and soils in the South		No	
SWC 7-d1	Improvement and management of saline and sodic soils of the Northern Plains	Grand Forks, N. Dak. Mandan, N. Dak. Newell, S. Dak.	Yes	7-C, D
SWC 7-e1	Saline and sodic soils and irrigation water quality problems in the Rio Grande River Basin	Weslaco, Tex.	Yes	7-B-1, D
SWC 7-18(e2)	Spectral reconnaissance for diagnosis of soil and water management problems	Weslaco, Tex.	Yes	7-F
SWC 7-f1	Soil and water management practices for the control or alleviation of saline and sodic soil problems in the Pacific Northwest	Ontario, Ore.	No	
SWC 7-g1	Effect of leaching, amendments, water quality, and soil and crop management practices on the soluble salt and adsorbed cation status of salt-affected southwestern soils	Riverside, Calif.	Yes	7-C
SWC 7-gF1	Mechanisms of reactions between dissolved and adsorbed constituents of salt-affected soils	Riverside, Calif.	Yes	7-A-1
SWC 7-gF2	Structure, organic matter, and microbial relations in salt-affected soils	Riverside, Calif.	Yes	7-A-2
SWC 7-gF3	Methods for the diagnosis and study of salinity in soils and water	Riverside, Calif.	Yes	7-A-3
SWC 7-gF4	Soil physical and chemical conditions in relation to plant growth on salt-affected soils	Riverside, Calif.	Yes	7-A-4
SWC 7-gF5	Tolerance of economic plants to salinity and exchangeable sodium	Riverside, Calif.	Yes	7-B-1
SWC 7-gF6	Plant-water relationships under saline, drought, or high exchangeable-sodium conditions	Riverside, Calif.	Yes	7-B-3
SWC 7-gF7	Effects of salinity and exchageable-cation status on absorption, distribution, and metabolic effectiveness of ions in plants	Riverside, Calif.	Yes	7-B-3
SWC 7-gF8	Effects on plants of specific ions associated with salinity or exchangeable sodium	Riverside, Calif.	Yes	7-B-4
SWC 7-gF9	Influence of climatic and edaphic factors on plant response to salinity and exchangeable sodium	Riverside, Calif.	Yes	7-B-1
SWC 7-gF10	Chemical composition of irrigation waters in relation to their suitability for use	Riverside, Calif.	Yes	7-C

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Work & Line Project Number	Work and Line Project Titles	Work Locations During Past Year	Line Project Incl. in Summary of Progress (Yes-No)	Area and Subheading
SWC 7-gF11	Principles of salinity control, including the amelioration of salt-affected soils by leaching and the use of amendments	Riverside, Calif.	Yes	7-E
A10-SWC-7	The response of plants to changing salinity	Jerusalem, Israel	Yes	7-B-3
A10-SWC-24	Development of methods for measuring partial vapor pressure in soil water	Haifa, Israel	No	
A10-SWC-30	Physiological adaptation of plants to moisture and osmotic stresses with respect to salt accumulation	Beersheva, Israel	No	
A10-SWC-31	Theoretical and experimental investigations of the mechanism of flow of water and solutes in plant roots	Jerusalem, Israel	No	

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Work & Line Project Number	Work and Line Project Titles	Work Locations During Past Year	Line Project Incl. in Summary of: Progress (Yes-No)	Area and Subheading
SWC 8	Water and wind erosion control principles, practices, systems, and prediction methods for conservation of crop and rangelands			
SWC 8-a1	Determination and evaluation of factors affecting water runoff and erosion in the different land resource areas of the Northeast as related to soil and water conservation practices	Orono, Me. Ithaca, N. Y.	No	
SWC 8-b1	Effects of soil, topography, climate, cropping and management procedures on runoff and erosion and on the prediction of soil losses in the South	Watkinsville, Ga. Tifton, Ga. Holly Springs, Miss.	Yes	4-D-1, 8-A-4, B-1, 3, D-3
SWC 8-b2	Development of supporting practices, systems, techniques and devices for runoff and erosion control in the South	Watkinsville, Ga.	Yes	8-A-1
SWC 8-c1	Basic principles and mechanics of rainfall, runoff, soil movement and loss in the Corn Belt	Urbana, Ill. Lafayette, Ind. Morris, Minn.	Yes	8-A-1
SWC 8-c2	Evaluation of climatic, topographic, soil and crop management factors in relation to water management and erosion control in the Corn Belt	Lafayette, Ind. Ames, Iowa Morris, Minn. Columbia, Mo. Madison, S. Dak. Lancaster, Wisc. Madison, Wisc.	Yes	4-D-1, 8-A-1, 4 B-1, C-1
SWC 8-c3	Development and refinement of methods for predicting field runoff and soil loss	Lafayette, Ind. Morris, Minn.	Yes	8-C-1
SWC 8-c4	Development of supporting runoff and erosion control practices and systems in the Corn Belt	Morris, Minn. Columbia, Mo. Madison, S. Dak.	Yes	8-D-3
SWC 8-8(d1) (Rev.)	Water and wind erosion and its control on irrigated and nonirrigated lands in the Northern Plains	Sidney, Mont. Lincoln, Nebr. Mandan, N. Dak. Rosemont, Nebr.	Yes	8-B-2, D-4
SWC 8-e1	Wind erosion control in the Southern Plains	Manhattan, Kans. Colby, Kans. Garden City, Kans. Hugoton, Kans. Alliance, Nebr. Hardesty, Okla. Big Spring, Tex. Bushland, Tex.	Yes	8-A-2, B-2, C-2, D-1, 2
SWC 8-10(e2) (Rev.)	Mechanics and principles of water erosion and their application for erosion control in the Southern Plains	Manhattan, Kans. Cherokee, Okla. Chickasha, Okla. Big Spring, Tex. Temple, Tex.	Yes	8-A-5, D-3, 5
SWC 8-f1	Erosion and runoff control practices and systems to conserve soil and water resources in the Pacific Northwest	St. Anthony, Ida. Pendleton, Ore. Pullman, Wash.	Yes	8-B-1
SWC 8-f2	Fundamental aspects of water erosion in the Pacific Northwest	Pullman, Wash.	Yes	8-A-3

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Work & Line Project Number	Work and Line Project Titles	Work Locations During Past Year	Line Project Incl. in Summary of: Progress (Yes-No)	Area and Subheading
SWC 9	Moisture conservation for the efficient and effective use of precipitation on crops and range lands.			
SWC 9-1(c1)(R)	Development of soil management systems for efficient use of soil moisture in the Corn Belt region.	Morris, Minn. Crookston, Minn. Madison, S. Dak. Brookings, S. Dak. Lancaster, Wisc.	Yes	9-A-1
SWC 9-d1	Improved water conservation and use on nonirrigated lands of the Northern Plains.	Akron, Colo. Fort Collins, Colo. Gunnison, Colo. Grand Junction, Colo. Bozeman, Mont. Sidney, Mont. Lincoln, Nebr. North Platte, Nebr. Mandan, N. Dak. Newell, S. Dak. Cottonwood, S. Dak. Laramie, Wyo.	Yes	9-A-2,3,4, B-1,2,3, C-1,4,7,8,9
SWC 9-e1	Conservation and efficient use of precipitation in the Southern Great Plains.	Bushland, Tex. Big Spring, Texas Weslaco, Texas	Yes	9-A-1,2, C-2,3
SWC 9-f1	Moisture conservation principles and practices in the Southern Great Plains.	Pendleton, Ore. St. Anthony, Idaho Newdale, Idaho	Yes	9-A-2
SWC 9-g1	Perfecting cropping sequences, land and water management systems, and cultural practices to conserve and efficiently utilize precipitation.	Riverside, Calif.	Yes	9-B-6, C-5,6
A10-SWC-32	Soil water evaporation and means of minimizing it.	Volcani Institute Agr. Res., Nat'l. & Univ. Insti. of Agriculture, Rehovot, Israel	Yes	9-B-5

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Work & Line Project Number	Work and Line Project Titles	Work Locations During Past Year	Line Project Incl. in Summary of: Progress (Yes-No)	Area and Subheading
SWC 10	Soil properties, processes and management in relation to the conservation and efficient use of land and water resources.			
SWC 10-a1	Development of improved soil management and conservation practices on croplands in different land resource areas of the Northeast.	Orono, Maine Marlboro, N.J. Marcellus, N.Y. Blacksburg, Va.	Yes	10-A-4, C-2,5
SWC 10-a2	Development of improved soil management practices for grassland soils in different land resource areas of the Northeast.	University Park, Pa.	Yes	10-A-3
SWC 10-36(a3)	Fixation of atmospheric nitrogen by rhizobia.	Beltsville, Md.	Yes	10-A-2
SWC 10-aB1	Fixation of ammonium ion in soils and its release to plants.	Beltsville, Md.	No	
SWC 10-aB2	Biological transformations of nitrogen in soil, including biological interchange in the rhizosphere, nonsymbiotic fixation, gaseous losses, and accumulation of toxic products.	Beltsville, Md.	Yes	10-A-3
SWC 10-aB3	Humus formation in soils and the interaction of organic compounds with clays.	Beltsville, Md.	Yes	10-D-2
SWC 10-aB4	Evaluation of soil-pesticide complexes, including their decomposition.	Beltsville, Md.	No	
SWC 10-aB6	Genetic studies with nitrogen-fixing organisms.	Beltsville, Md.	No	
SWC 10-aB7	The relationship between the soil as the source of nutrients and the ion uptake process in the plant.	Beltsville, Md.	Yes	10-B-1
SWC 10-aB8	Nutrient balance for plant growth as related to soil environment, plant species and variety, and the nature of added nutrient carriers.	Beltsville, Md.	Yes	10-B-1
SWC 10-aB9	Development of spectrochemical methods and foliar diagnostic procedures for soil and plant investigations.	Beltsville, Md.	Yes	10-B-2
*SWC 10-37 (aB10)	Physical chemistry of potassium availability in soils.	Beltsville, Md.	No	
SWC 10-38 (aB11)	The effects of pesticides and other chemical contaminants on microbial processes in soils.	Beltsville, Md.	No	
SWC 10-39 (aB12)	The agricultural significance of certain transitional elements derived from pesticides and other agricultural chemicals.	Beltsville, Md.	Yes	10-B-2
**SWC 10-43 (aB13)	Development of analytical chemical methods in soil science research.	Beltsville, Md.	No	

*Project discontinued May 10, 1965.
**Project approved April 25, 1966.

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Work & Line Project Number	Work and Line Project Titles	Work Locations During Past Year	Line Project Incl. in Summary of: Progress (Yes-No)	Area and Subheading
SWC 10-b1	The lime requirements of red and yellow podzolic and related soils.	Jayuya, Orocovis, & Rio Piedras, P.R.	Yes	10-B-1
SWC 10-b2	The fertility requirement of exposed subsoils.	Adjuntas & Maricao, Puerto Rico	Yes	10-A-4
SWC 10-b3	Fertilization for efficient crop production under intensive management.	Thorsby, Alabama Fayetteville, Ark. Fleming, Ga. Watkinsville, Ga. Jayuya, P. Rico Orocovis, P. Rico	Yes	10-A-3
SWC 10-b4	Developing improved cropping systems for soil conservation.	Watkinsville, Ga. Puerto Rico (island wide)	Yes	10-A-3, C-5
SWC 10-b5	Crop residue management and tillage practices for soil conservation and efficient production in the South.	Thorsby, Ala. Watkinsville, Ga. Rio Piedras, P. R. Florence, S. C.	Yes	10-B-2, C-2,4, D-1
SWC 10-b6	Factors influencing crop rooting development and activity and means of increasing root development in the South.	Auburn, Ala. Thorsby, Ala. Florence, S. C.	Yes	10-A-2, B-1, C-2; 11-A-6
SWC 10-b7	Integration of improved practices for soil and water conservation in the South.	Watkinsville, Ga. Fleming, Ga.	No	
SWC 10-c1	Moisture utilization in the Corn Belt as influenced by soil fertility level and management practices.	Ames, Iowa Morris, Minn. Elsberry, Missouri	No	
SWC 10-c2	Tillage practices and crop residue management for soil conservation and efficient production in the Corn Belt.	Ames, Iowa Morris, Minn. Crookston, Minn. Columbia, Mo. Madison, S. Dak. Lancaster, Wisc. Madison, Wisc.	Yes	10-C-2
SWC 10-c3	Fundamental studies on the mechanism of soil structure formation in the Corn Belt.	St. Paul, Minn. Madison, Wisc.	Yes	10-B-3, C-1,2
SWC 10-d1	Chemical reactions and availability of phosphates in Northern Plains soils as affected by fertilization, soil properties, and management.	Mandan, N. Dak. Grand Junction, Colo. Bozeman, Mont. Huntley, Mont. Ft. Collins, Colo.	Yes	10-A-3,5
SWC 10-d2	Soil nitrogen transformations in relation to soil nitrogen maintenance and more efficient use of fertilizer nitrogen in the Northern Plains.	Huntley, Mont. Laramie, Wyo. Newell, S. Dak. Mandan, N. Dak. Ft. Collins, Colo. Grand Junction, Colo.	Yes	10-A-1,2,3, D-2
SWC 10-d3	Fertilizer requirements and fertility status of Northern Plains soils for more efficient crop and forage production.	Ft. Collins, Colo. Gunnison, Colo. Newell, S. Dak. Laramie, Wyo. Mandan, N. Dak. Sidney, Mont.	Yes	10-A-3,4,5
SWC 10-d4	Improved soil management practices and systems for better conservation farming in the Northern Plains.	Akron, Colo. Ft. Collins, Colo. Grand Junction, Colo. Sidney, Mont. Mandan, N. Dak. Newell, S. Dak.	No	

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Work & Line Project Number	Work and Line Project Titles	Work Locations During Past Year	Line Project Incl. in Summary of: Progress (Yes-No)	Area and Subheading
SWC 10-d5	Principles and practices of stubble-mulch maintenance for soil and water conservation in the Northern Plains.	Akron, Colo. Bozeman, Mont. Sidney, Mont. Lincoln, Nebr. North Platte, Nebr.	Yes	10-C-4, D-1
SWC 10-40(d7)	Chemical, physical, and biological reactions of pesticides with soils affecting soil productivity and pesticide stability.	Ft. Collins, Colo.	Yes	10-B-2
SWC 10-e1	Interrelationships between soil structure and plant growth.	Bushland, Tex. Big Spring, Tex. Temple-Riesel, Tex.	Yes	10-C-1,3
SWC 10-e2	Nutritional requirements for cropland and rangeland in the Southern Great Plains.	Bushland, Tex. Temple, Tex. Weslaco, Tex. Cherokee, Okla.	Yes	10-A-3,4, C-3
SWC 10-f1	Soil management practices for conservation farming in the Pacific Northwest.	Pullman, Wash. Pendleton, Ore. St. Anthony, Idaho Twin Falls, Idaho Prosser, Wash.	Yes	10-A-5, C-3,4,6
SWC 10-f2	Chemistry and availability of nutrient elements in soils of the Pacific Northwest.	Pendleton, Ore. Corvallis, Ore. Twin Falls, Idaho Prosser, Wash.	Yes	10-A-2,3,4,5, C-5
SWC 10-f3	Chemistry and effects of organic matter in soils of the Pacific Northwest.	Corvallis, Ore. Twin Falls, Idaho	Yes	10-A-2
SWC 10-f4	Microbial equilibria in soils of the Pacific Northwest.	Prosser, Wash.	Yes	10-D-2
SWC 10-g1	Principles of nutrient uptake and efficient fertilizer use in relation to moisture regime and irrigation practice, soil properties and crop nutrient requirements in the Southwest.	Brawley, Calif. Tucson, Ariz. Logan, Utah	Yes	10-A-3, C-1; 11-A-6
SWC 10-g2	Improvement of soil fertility, crop production and soil and water conservation through the use of fertilizers and soil amendments on rangeland and nonirrigated cropland in the Southwest.	Riverside, Calif.	Yes	9-C-10
SWC-0-0-1(AEC)	Soil chemistry and radioactive contamination in soils and plants.	Beltsville, Md.	Yes	10-B-3
A7-SWC-7	A study of the soil algae of the rice fields and their contribution to the fertility of the soil.	U. of Allahabad, Allahabad, India	No	
A7-SWC-17	Iron and molybdenum as plant nutrients.	U. of Lucknow, Lucknow, India	No	
A7-SWC-29	Investigations on soil structure as influenced by organic matter with the help of microscopic and other techniques.	Indian Agr. Res. Insti., New Delhi, India	No	

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Work & Line Project Number	Work and Line Project Titles	Work Locations During Past Year	Line Project Incl. in Summary of Progress (Yes-No)	Area and Subheading
A7-SWC-33	Ecological specialization of micro-organisms native to 'Usar' (alkaline) soils of India.	Lucknow U., Lucknow (U.P.), India	No	
A7-SWC-47	The influence of oxygen level and mechanical impedance as related to the plant growth and tillage requirements of flooded paddy.	Indian Insti. of Technology, Kharagpur, India	No	
A10-SWC-1	Agricultural utilization of soils affected by salinity.	Hebrew U., Rehovot, Israel	Yes	10-A-3
A10-SWC-8	Mode of occurrence of minor elements in sediments and soils: A fundamental study for the understanding of the behavior and distribution of minor elements in soils.	Hebrew U. of Jerusalem, Israel	No	
A10-SWC-12	The determination of available microelements in calcareous soils.	Hebrew U., Rehovot, Israel	No	
A10-SWC-15	Micro-heterometric methods for the quick and precise determination of trace elements in agriculture.	Hebrew U. of Jerusalem, Israel	No	
A10-SWC-22	Basic and applied research into efficiency of phosphate fertilization.	Technion-Israel Insti. of Technology, Fertilizer Development & Soil Fertility Lab., Haifa, Israel	No	
A10-SWC-27	The movement of ions and salts through non-ideal porous media (as applied to problems of salt leaching and fertilizer distribution in soil profiles).	Technion Israel Insti. of Technology, Haifa, Israel	No	
A10-SWC-38	Fixation and availability of added phosphorus in soils as a function of bulk movement and diffusion.	Technion - Israel Insti. of Technology, Fertilizer & Soil Fertility Lab., Haifa, Israel	Yes	10-A-3
E21-SWC-2	Fundamental studies of reactions between mineral and organic components in soil.	College of Agri., Wroclaw, Poland	Yes	10-D-3
E21-SWC-3	Studies on the variability and genetics of Rhizobium. (Grant terminated as scheduled 5-24-65)	M.Curie-Sklodowska U., Lublin, Poland	No	
E21-SWC-7	Distribution of micronutrient elements among soil minerals. (Grant terminated as scheduled 10-30-65)	The Insti. of Soil Sci. & Plant Cultivation, Pulawy, Poland	Yes	10-A-5
E25-SWC-7	Study of the retention of some substances of insecticidal and weed-controlling potential by the principal specific clay constituents, and relation of that retention to the specific surface area of the clay constituents, moisture and temperature.	U. of Granada, Granada, Spain	No	

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Work & Line Project Number	Work and Line Project Titles	Work Locations During Past Year	Line Project Summary of Progress (Yes-No)	Incl. in Area and Subheading
SWC 11	Soil, water, and plant relations as they affect use of land and water resources.			
SWC 11-a1	The energy budget at the earth's surface.	Ithaca, New York	Yes	11-B-4
SWC 11-b1	Modification of soil surface structure and crop geometry to beneficially influence climatic conditions in the South.	State College, Miss	Yes	11-C-2
SWC 11-b2	Plant factors influencing transpiration in the South.	Watkinsville, Ga.	Yes	11-B-4
SWC 11-c1	Soil moisture-plant growth relationships in the Corn Belt.	Urbana, Ill. St. Paul, Minn.	Yes	11-A-5
SWC 11-c2	Climatic influence on water use and crop performance in the Corn Belt region.	Urbana, Ill. Morris, Minn.	Yes	11-B-1, C-1
SWC 11-c3	Soil moisture flow problems and solutions in the Corn Belt region.	Urbana, Ill. Brookings, S. Dak.	Yes	11-A-3
SWC 11-d1	Principles affecting soil structure stability and its effect on aeration intake, transmission, and storage of water on irrigated lands in the Northern Plains.	Fort Collins, Colo. Grand Junction, Colo.	Yes	11-A-1,6
SWC 11-e1	Understanding and improving soil-plant-atmospheric relationships for more efficient utilization of water.	Big Spring, Tex. Bushland, Tex. Weslaco, Tex. Temple-Riesel, Tex.	Yes	11-A-5,6 B-2,3
SWC 11-13(g1)	Physical processes affecting soil water and their relationship to physiological functioning of plants.	Davis, Calif. Brawley, Calif. Riverside, Calif.	Yes	11-A-2,4
SWC 11-gF1	Physical properties and kinetics of change of the physical properties of water in soil-water systems.	Riverside, Calif.	Yes	11-A-2
SWC 11-gG1	Uptake and disposal of water by plants in an arid climate.	Phoenix, Arizona	Yes	11-B-4

Line Project Check List -- Reporting Year April 1, 1965, to March 31, 1966

Work & Line Project Number	Work and Line Project Titles	Work Locations During Past Year	Line Project Incl. in Summary of Progress (Yes-No)	Area and Subheading
SWC 12	Nutrition of animals as affected by properties and characteristics of soils and plants.			
SWC 12-aA1	Studies of the effects of soil and geological conditions on the composition of forages and other crops in relation to nutritional problems in animals.	Ithaca, New York	Yes	12-D-1,2
SWC 12-aA2	Effect of environment, soil type, and soil management on the nutritive quality of crops as measured by animal growth, health, and reproduction.	Ithaca, N. Y. Tifton, Ga. Reno, Nev.	Yes	12-C-1,2
SWC 12-aA3(c)	Micronutrient elements of soils and plants in relation to certain endemic nutritional diseases of animals.	Ithaca, N. Y. Corvallis, Ore.	Yes	12-B-2,3,4
SWC 12-aA4	The role of mineral elements, enzymes, nucleic acids, and other factors on the biosynthesis of proteins.	Ithaca, N. Y.	Yes	12-A-1
SWC 12-aA5	Chemical reactions of micronutrient cations with clay minerals and plant extracts.	Ithaca, N. Y.	Yes	12-E-1
SWC 12-aA6	Toxicities in food and forage plants with particular reference to nitrates and certain mineral elements.	Inactive	No	
SWC 12-aA7	Effect of plant nutrients and other mineral elements on the amino acid and protein content of food and forage plants.	Ithaca, N. Y.	Yes	12-A-2
SWC 12-aA8	The role of mineral elements in the formation of the organic matrix of bone.	Ithaca, N. Y.	Yes	12-B-1